METAVERSE BASED LEARNING
WITH MIXED REALITY
FOR PHYSICS EDUCATION USING
CONSTRUCTIVISM APPROACH

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METAVERSE BASED LEARNING WITH MIXED REALITY FOR PHYSICS EDUCATION USING CONSTRUCTIVISM APPROACH

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Science (Honours) Software Engineering

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"METAVERSE BASED LEARNING WITH MIXED REALITY FOR PHYSICS EDUCATION USING CONSTRUCTIVISM APPROACH"** was prepared by **AGNES TAN SZE WEI** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Science (Honours) Software Engineering at Universiti Tunku Abdul Rahman.

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ABSTRACT

This project presents the development of a metaverse-based Physics learning platform that leverages mixed reality (MR) technologies through a constructivist approach to enhance student engagement and deepen understanding. The platform is designed to address the challenges of traditional Physics education, such as the difficulty in visualizing abstract concepts and limited engagement in static learning environments. By integrating immersive mixed reality (MR) experiences, this project aims to provide a more interactive, intuitive, and engaging approach to learning key Physics concepts, specifically focusing on Free Fall Motion and Force. The platform is structured around five core modules: (1) a Tutorial Module for conceptual understanding, (2) a Hands-on Experiment Module to enable practical application through experiential learning, and (3) Interactive Assessment Modules to reinforce learning through assessments. In addition, (4) gamification elements, such as badges, and XP systems, are integrated to incentivize participation and motivate students. Furthermore, (5) a collaborative learning space module, powered by Gather.Town, encourages peer-to-peer interaction and discussion, reflecting the constructivist emphasis on social learning and shared knowledge construction.

The development process follows the ADDIE methodology, ensuring a structured approach from analysis to evaluation. The platform integrates the XR Interaction Toolkit in Unity for VR-based experiments, includes a responsive UI/UX design, and supports multiple devices for flexibility. Usability and system performance were evaluated using SUS and PSSUQ tests, alongside participants' assessment scores and feedback on the platform, revealing high usability, satisfaction, and enhanced learning performance in understanding complex Physics concepts. The results confirmed the platform's quality and effectiveness while highlighting areas for improvement in future iterations.

This project demonstrates the transformative potential of MR technologies in enhancing student engagement and promoting knowledge construction in Physics education. By aligning with the principles of constructivism, it provides a revolutionary, learner-centered approach to mastering complex Physics concepts, making abstract ideas more accessible and engaging through immersive, interactive learning.

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CHAPTER 1

INTRODUCTION

1.1 Introduction of the Project

The author endeavours to revolutionize Physics education through the integration of mixed reality (MR) technology, aiming to address the challenges associated with traditional teaching methods. By immersing students in dynamic and interactive learning environments, MR applications enable them to visualize complex Physics concepts, conduct virtual experiments, and engage in hands-on exploration. This approach not only fosters deeper understanding and engagement but also cultivates critical thinking and problem-solving skills.

Moreover, the author seeks to enhance assessment practices by implementing dynamic assessment tools within MR applications, providing real-time feedback and motivational quotes to students, and facilitating targeted interventions to address learning gaps. Ultimately, the project aims to create a metaverse-based learning platform that leverages MR technology and constructivist learning principles to empower students and enhance their learning experiences in Physics education.

1.2 Background Study

The project's background study delves into the concept of the metaverse, the dynamic evolution of Physics education, the immersive realm of mixed reality, and the constructivism approach. While providing a fundamental knowledge, the initial study serves as a precursor to the more in-depth analysis included in Chapter 2's literature review, in which each topic will be meticulously studied and contextualised within relevant academic discourse.

1.2.1 The “Metaverse”

Figure 1.1: A virtual, multiuser platform and the view of the user in real life.

Source: Marr (2023)

"Metaverse", an emerging digital universe created by merging virtual reality (VR) and augmented reality (AR) technologies (Mystakidis, 2022). This dynamic and interconnected space transcends traditional boundaries, offering users immersive experiences where they can interact with virtual environments, objects, and fellow users in real-time.

Today, the Metaverse is not only confined to gaming but has expanded its reach into various fields, including retail, business, art, healthcare, and more. The Metaverse holds immense potential for reshaping how people interact, learn, communicate, entertain, and do business in a variety of fields (Gilani, 2024).

Its significance comes from its ability to offer multisensory interactions, persistent multiuser environments, and embodied communication (Mystakidis, 2022), all of which promote creativity, teamwork, and accessibility to a wide range of experiences that were previously unattainable in the physical world. From educational simulations to virtual events and beyond, the Metaverse represents a transformative force poised to reinvent human interaction and engagement in the digital age.

1.2.2 The Evolution of Physics Education

The evolution of Physics education has undergone a remarkable transformation over the centuries, driven by advancements in scientific understanding, changes in educational philosophy, and the integration of technology into teaching methods. In the classical period, Physics education was primarily theoretical, focusing on the works of ancient scholars like Aristotle and Archimedes (Helenthehare, 2019). The teaching was often reliant on static textbooks and lectures. However, with the advent of the experimental revolution during the Renaissance, there was a notable shift towards hands-on experimentation, epitomized by figures like Galileo Galilei (Helenthehare, 2019). This period marked the beginning of practical Physics education, with students actively engaged in conducting experiments to explore natural phenomena, laying the foundation for modern experimental Physics.

The subsequent mathematical formalism introduced by luminaries like as Newton in the 17th century brought a new level of rigor to Physics education Helenthehare, 2019). This period saw a deep integration of mathematical concepts into the study of Physics, enabling precise descriptions of physical laws and phenomena. As Physics continued to advance, the curriculum evolved to incorporate new theories such as electromagnetism and thermodynamics, expanding beyond universities to secondary schools and making Physics education more accessible to a broader audience.

The quantum revolution in the early 20th century marked another pivotal moment in the evolution of Physics education (Intonti et al., 2024). The introduction of quantum mechanics challenged traditional notions of Physics (Intonti et al., 2024), necessitating new pedagogical approaches to convey abstract concepts like wave-particle duality and uncertainty. Subsequent developments, such as the emergence of computational Physics and the integration of technology into education, have further transformed the landscape of Physics learning.

Today, Physics education emphasizes inquiry-based learning, interdisciplinary connections, and inclusive practices, rather than passive recipients of information (Fan and Ye, 2022), reflecting a dynamic interplay between scientific progress, pedagogical innovation, and societal needs. Innovations such as mixed reality (MR) technology have emerged as potent tools, offering immersive experiences that enable students to visualize complex phenomena, conduct virtual experiments, and explore Physics principles in tangible ways. As our understanding of the physical world continues to deepen, Physics education will undoubtedly continue to evolve. The integration of MR and other immersive technologies shows potential for fostering active learning, critical thinking, and problem-solving skills essential for navigating the complexities of the modern world, preparing students to tackle the challenges and opportunities of the future with confidence and proficiency.

1.2.3 Mixed Reality

Mixed reality (MR) is a cutting-edge technology that blends elements of virtual reality (VR) and augmented reality (AR) to create immersive and interactive digital experiences (Aloqaily et al., 2023). MR allows users to interact with both real and virtual worlds simultaneously (Tremosa, 2023), seamlessly integrating digital content into the physical environment. It harnesses the power of cloud computing and artificial intelligence to create immersive experiences (BasuMallick, 2022). According to BasuMallick (2022), the MR content can be accessed through mobile devices, heads-up display, 360-degree environment or MR glasses. MR technology is widely used in various industries, including healthcare, education, entertainment industry, engineering and manufacturing, and retail sector.

This technology has emerged as a powerful tool for education, offering unique opportunities to enhance learning experiences across various disciplines, including Physics education. By enabling students to visualize abstract concepts, conduct virtual experiments, and engage in hands-on learning activities, MR holds the potential to transform traditional teaching methods and facilitate deeper understanding of complex scientific principles. As MR continues to evolve and become more accessible, educators are exploring innovative ways to harness its capabilities to create dynamic and engaging learning environments that inspire curiosity, creativity, and critical thinking among students. Through the integration of MR technology, the author aims to revolutionize Physics education by providing students with immersive and interactive experiences that promote active learning, experimentation, and exciting discovery journey.

1.2.4 The Constructivism Approach

The constructivism approach to learning, rooted in cognitive psychology and educational theory (Bada and Olusegun, 2015), emphasizes active knowledge construction through experiential learning. It proposes that learners actively build their understanding of the world by interpreting and organizing their experiences, as well as incorporating new knowledge into their mental models rather than passively receiving information (Mcleod, 2024). This approach acknowledges the importance of prior knowledge, social interaction, and real-world context in forming meaningful connections between prior knowledge, new knowledge, and the learning processes that influence learning outcomes (Mcleod, 2024).

Constructivism aspires to foster deeper understanding, critical thinking skills, and metacognitive awareness by engaging learners in authentic tasks, problem-solving activities, and collaborative discussions. This learner-centered approach (Serin, 2018) has gained prominence in education due to its potential to promote meaningful learning experiences and long-term retention of knowledge. As educators seek to create dynamic and interactive learning environments, the constructivist principles continue to inform instructional practices, curriculum design, and the integration of technology to support diverse learning needs and styles.

1.3 Problem Statement

In this section, an overview of the problem statement will be provided, highlighting the key issues and challenges addressed in the research. The author delves into the core problem areas identified, offering insights into the significance of the research questions and the broader implications for the field. Through this overview, readers will gain a clear understanding of the central focus of the study and the rationale behind its exploration.

1.3.1 Difficulty in Visualising Abstract Concept in Physics

The concepts and objects in the Physics world are difficult to visualize and explain due to their abstract nature (Gong, 2015). Studies have shown that students with low spatial ability students have been demonstrated to have difficulty learning Physics, especially when it comes to solving problems which require for visualising abstract Physics concepts (Kozhevnikov and Thornton, 2006). This may result in students with low spatial ability having a shallow understanding and memorization of Physics principles. Fortunately, visualisation tools such as simulations offer an advantage in assisting students establish a conceptual grasp of Physics knowledge by enabling them to visualise complex phenomena and make sense of abstract concepts (Gong, 2015). In the implementation of mixed reality technology in the Physics classroom, the project entails developing custom MR applications and simulations, tailored to the curriculum, enabling students to interact with virtual objects, conduct experiments, and explore Physics phenomena in a dynamic and engaging manner. The flexibility of this dynamic environment offers students considerable freedom to experiment with different approaches to problems, which not only enhances their fluency (their ability to generate multiple ideas) but also strengthens their flexibility (the ability to view problems from multiple perspectives) during the problem-solving process (Dusabimana & Rugema, 2022). By integrating MR technology, educators can strengthen students' problem-solving and idea-generation skills, promote active learning, and improve their conceptual understanding of Physics principles, ultimately better preparing students for future academic and professional pursuits.

1.3.2 Limitation of Linear Interface and Physical Space

In the realm of Physics education, traditional simulation interfaces are typically characterized by a linear design, confining students to predetermined pathways and limiting their exploration of concepts and constraining their experimentation and inquiry into complex phenomena within virtual environments. This constraint often leads to disengagement and frustration among students. Similarly, overcrowded classrooms further exacerbate the situation by lacking sufficient instructional resources and space for hands-on learning experiences, hindering effective teaching and collaborative activities, thereby compromising the overall quality of the learning experience (Muhammad Zaman et. al., 2023). The integration of constructivist learning theory, which emphasizes learning through reflection on experience by interacting with surroundings (Matriano, 2020), is impeded by these limitations in both linear interfaces and limited physical space, presenting significant challenges for implementing immersive experimental learning experiences. To address these challenges, mixed reality (MR) technology offers transformative solutions. MR interfaces, unlike traditional 2D interfaces seen in computers or mobile devices, allow users to interact with digital objects in dynamic 3D environments by overlaying virtual material onto their surroundings. By transcending physical constraints, MR facilitates immersive learning experiences and virtual collaboration, fostering teamwork and equal participation. Furthermore, transitioning from linear to spatial interfaces enhances students' comprehension and retention of Physics knowledge, by enabling them to interact with simulations and conduct practical experiments in large-scale more effectively.

1.3.3 Limited Engagement in Traditional Physics Education

Traditional Physics education often presents challenges for educators in providing engaging learning environments for students and assessing student progress. Conventional teaching approaches frequently rely on static textbooks and lectures, which may not fully captivate students' interest or cater to their diverse learning styles (visual, auditory, kinesthetic). According to Shaidullina et. al. (2023), some students may have a dominant learning style, which makes it difficult for them to fully engage with standardised learning materials that do not match their preferred learning style, leading to disengagement and passive learning behaviours, as well as uneven learning outcomes. Moreover, traditional assessment methods often fall short in accurately measuring student understanding, particularly in crowded classrooms, due to constraints of time and workload for educators (Muhammad Zaman et. al., 2023). This limitation reduces educators' ability to provide timely guidance and feedback to students, causing them to lose interest and feel disengaged during prolonged waiting periods for support. In contrast, by incorporating innovative instructional approaches such as MR technology offer dynamic and interactive learning environments that inspire curiosity and critical thinking, fostering deeper engagement and motivation among students. One possible method to address these challenges is to develop gamified MR applications that leverage game mechanics and interactive elements to motivate student participation, encourage exploration, and reward progress and achievement. By gamifying MR experiences, educators can transform the Physics classroom into an engaging and immersive learning environment, where students are actively involved in problem-solving, experimentation, and discovery, resulting to increased motivation, deeper engagement, and improved learning outcomes. Additionally, the dynamic assessment tools within the gamified elements, such as tutorials and quizzes, adapt to students' interactions and provide real-time feedback, enabling educators to assess student progress and understanding precisely, as well as address learning gaps and misconceptions more effectively; hence, allowing for focused interventions that elevate student learning outcomes and achievement in Physics education.

1.4 Project Objectives

The project objectives aim to define the scope and purpose of the endeavour, guiding its direction and outcomes. These objectives serve as a roadmap for achieving specific goals and milestones, ensuring clarity and alignment throughout the project lifecycle. By outlining clear and measurable objectives, efforts and resources can be allocated effectively, and success can be evaluated against predetermined criteria. The objectives are as follow:

1.4.1 To study the use of mixed reality technologies in Physics education through a constructivist approach

This objective aims to systematically study the application of mixed reality (MR) technologies—specifically Virtual Reality (VR) and Augmented Reality (AR)—in various educational settings, with a particular focus on enhancing Physics education. The study will analyse the existing literature, tools, and platforms used in educational settings, while also exploring the importance of the constructivist approach in promoting active and experiential learning. The effectiveness of these technologies will be evaluated through case studies, and comparative analysis of existing technologies used in Physics education, such as VR, AR, and simulations. Success will be measured by identifying key challenges, benefits and best practices for integrating MR technologies and the constructivist approach. By the end of the study, the project aims to provide actionable insights into how MR technologies can improve learning performance, particularly in line with constructivist learning principles.

1.4.2 To develop a metaverse-based learning platform for Physics using mixed reality technologies and constructivist principles

The goal is to design and develop a fully-functional metaverse-based learning platform that integrates mixed reality (MR) technologies, specifically VR and AR, employing a constructivist approach to enhance the learning of Physics concepts. The platform will provide an immersive and interactive learning experience, addressing the challenges faced in traditional education. By incorporating features such as virtual experiments, gamification elements, collaborative learning spaces, interactive simulations and assessments, the platform aims to create a dynamic and engaging environment for Physics education. The development process will follow a systematic methodology to ensure an efficient, user-friendly, and responsive platform, with clearly defined milestones throughout the project lifecycle. Success will be measured by the platform's ability to offer an intuitive, engaging, and effective learning experience, allowing users to perform all functions and modules with minimal issues.

1.4.3 To evaluate the effectiveness of mixed reality technologies on students’ learning performance in Physics education

This objective focuses on assessing the impact of mixed reality (MR) technologies on key aspects of student learning performance, including engagement, motivation, conceptual understanding, retention of Physics concepts, and the overall educational experience. Effectiveness will be evaluated through observation, usability testing and user feedback from both students and educators. Specific tools include formative assessments embedded within the application, such as quizzes in the interactive assessment module, with progress tracked through the gamification module (XP, assessment scores, and badges earned). Additionally, SUS and PSSUQ feedback will be collected to evaluate user satisfaction and improvements in retention and concept mastery. The goal is to achieve statistically significant improvements in students' learning performance, focusing on increased engagement and conceptual understanding, as demonstrated through both quantitative data and qualitative insights gathered from user observation and feedback.

1.5 Project Scopes

The comprehensive scope of the project covered by this application, consists of five modules, outlining the numerous features and functionalities it offers.

1.5.1 Modules / Features

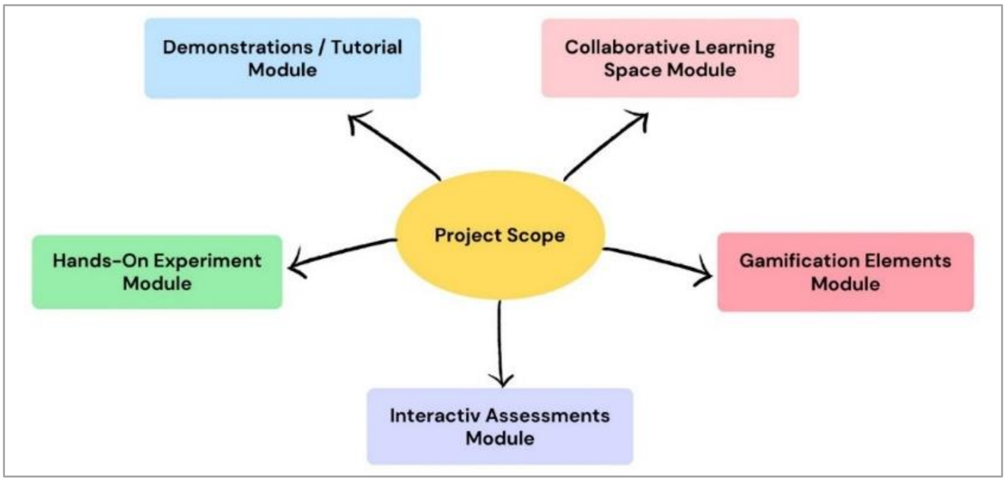


Figure 1.2: Project Scope

Source: Created by the author

Figure 1.2 illustrates the scope of the project covered by this application, which consists of five modules that outline the features and functionalities it offers. This project will cover the Malaysia KSSM Form 4 Physics syllabus, with a particular focus on the topics of **Force** and **Free Fall Motion**, as these concepts are fundamental to understanding more advanced principles in Physics and often require interactive methods for better comprehension. The modules' explanations are as follows:

1.5.1.1 Conceptual Demonstrations / Tutorial Module

This module integrates conceptual demonstrations of abstract Physics principles, utilizing augmented reality (AR), 3D animations, sound, graphs, and interactive presentations to visually explain complex topics such as mechanics, thermodynamics, and electromagnetism. The dynamic nature of these presentations helps students of varying spatial abilities engage with challenging concepts, enhancing their comprehension and encouraging deeper exploration. By bridging the gap between theoretical concepts and real-world applications through visually engaging content, students develop a more intuitive understanding of fundamental Physics principles, fostering a foundation for further exploration and mastery of the subject.

1.5.1.2 Hands-on Experiment Module

The virtual hands-on experiments module offers an immersive 3D virtual laboratory environment that replicates real-life scenarios using virtual reality (VR), enabling students to conduct interactive virtual experiments, manipulate variables, collect data, and analyse results within a safe and controlled digital space. This module also allows users to explore the behaviour of objects from micro to macro perspectives by adjusting predefined parameters. Leveraging mixed reality technologies and aligned with the constructivist learning theory, this module encourages active knowledge construction through hands-on virtual experimentation and observation. Students can better visualize and comprehend abstract Physics concepts by observing them unfold in real-time simulations.

1.5.1.3 Interactive Assessments Module

Interactive assessments and quizzes embedded within the application serve a means to assess student comprehension and progress in real-time, delivering immediate feedback based on individual performance. Users can access the quiz environment where they will encounter questions to solve, with marks calculated and feedback provided accordingly. This approach not only helps reinforce learning but also enhances information retention, thereby boosting students' confidence and motivation. The instant feedback mechanism prevents students from disengaging during prolonged waiting periods for teacher feedback, empowering them to self-assess strengths and weaknesses and fuelling their determination to enhance their understanding of the subject matter.

1.5.1.4 Gamification Elements Module

Incorporating gamification elements like experience points (XP), leaderboards, badges and rewards, this module aims to incentivize student engagement and motivate learning by offering interactive challenges and competitions. As students progress through tutorials, engage in hands-on experiments, or excel in assessments and quizzes, they are duly rewarded with XP, marks and badges, fostering a sense of achievement and progress. Additionally, students can participate in competitions via Kahoot, with leaderboards showcasing top performers, fostering healthy competition among peers. Through gamification, students are encouraged to actively participate in problem-solving, decision-making, and overcoming challenges, which can contribute to a more hands-on and practical learning experience. By infusing elements of play into the learning process, gamification significantly enhances student engagement, transforming learning into a fun and interactive experience. This approach helps sustain interest and motivation, ultimately cultivating a positive attitude towards learning.

1.5.1.5 Collaborative Learning Spaces Module

The Collaborative Learning Spaces Module is designed to facilitate interactive and engaging learning experiences by allowing multiple students to interact simultaneously within the application. This module creates virtual spaces through Gather.Town platform where students can collaborate, communicate, and share knowledge in real-time, fostering teamwork and peer collaboration. Students could work together in teams to complete collaborative projects, solve complex Physics problems, or participate in Physics-related competitions within the metaverse. Through this module, students can engage in cooperative learning activities, exchange ideas, and collectively explore Physics concepts in a dynamic and immersive environment. The collaborative nature of the module promotes active participation, encourages peer-to-peer interaction, and enhances the overall learning experience by providing students with opportunities to learn from each other's perspectives, skills, and expertise. Additionally, by working collaboratively, students develop important teamwork and communication skills, which are essential for success in both academic and professional settings.

1.6 Target Audience

The target audience for this project is Malaysian high school students in the science stream, specifically Form 4 students. At this stage, students are transitioning from the general science curriculum to more specialized subjects like Physics, chemistry, and biology. This phase introduces them to various new concepts and theories in Physics, which can be both exciting and challenging.

In their traditional classroom learning environment, students typically engage with textbooks and lectures as teachers introduce topics and guide them through notetaking and assessments. Alongside theoretical classes, students also participate in laboratory sessions where they conduct experiments under the guidance of their teachers. While some teachers may employ simulations for complex or hazardous experiments, these simulations often have limitations such as linear interfaces or unrealistic and less comprehensible representations.

Leveraging mixed reality (MR) technology for visualization purposes holds immense potential in enhancing their understanding of these concepts. By integrating MR into their learning experiences, students can gain a deeper comprehension of abstract Physics principles, making complex theories more accessible and engaging.

1.7 Proposed Solution and Limitation of the Study

This project consists of five modules designed to address key topics in Physics education, focusing specifically on the "Force and Motion" topic and tailored for Form 4 students. The modules include (1) Conceptual Demonstrations or Tutorial, providing visual explanations of abstract Physics principles; (2) Virtual Hands-on Experiments, offering immersive 3D virtual laboratory environments for interactive experimentation through mixed reality (MR) technology; (3) Interactive Assessments and Quizzes, offering real-time feedback and adaptive learning experiences; and (4) Gamification elements, incorporating game mechanics and interactive elements to motivate student participation, encourage exploration, and reward progress and achievement; (5) Collaborative Learning Spaces, facilitating teamwork and peer collaboration through multi-user interactions.

However, despite the innovative features and capabilities of the proposed solution, there are certain limitations to consider in the proposed solution. Firstly, due to the scope of the project and resource constraints, the modules are limited to covering the Force & Motion topic within the Form 4 curriculum, and further research and development may be needed to expand the application to cover additional topics or grade levels. Additionally, the system may face hardware constraints, as access to MR devices such as VR headsets or AR glasses may be limited due to cost or infrastructure constraints, affecting the implementation and accessibility of the proposed solution. Furthermore, the effectiveness of the proposed solution may vary depending on factors such as technical proficiency of users and their individual learning preferences. Despite these limitations, the proposed solution represents a significant step towards leveraging MR technology to enhance Physics education and create more engaging learning experiences for students.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

In this chapter, the author will delve into an exploration of key concepts central to the project's focus, including the metaverse, mixed reality, and constructivism theory. It offers a detailed overview of these concepts, methodologies, and findings in the field, serving as a foundation for understanding the current state of knowledge and identifying gaps or areas for further exploration, thus laying the groundwork for subsequent research endeavours and project development.

2.2 Metaverse

Figure 2.1: The "Metaverse"

Source: Bhatt (2023)

The term "Metaverse" – combination of the prefix "meta," which means "beyond," with the term "universe" (Bhatt, 2023), refers to a post-reality universe created by the convergence of technologies such as virtual reality (VR) and augmented reality (AR), enabling diverse sensory interactions with virtual environments, digital entities, and individuals (Mystakidis, 2022). It represents a persistent and interconnected multiuser space, seamlessly intertwining elements from the physical reality with those of the digital virtuality (Mystakidis, 2022). Within the Metaverse, users can engage in dynamic interaction and embodied communication with digital artifacts in real-time through immersive interactions. However, according to Bhatt (2023), recent technological improvements have made it more lifelike than ever. The integration of blockchain technology with virtual reality (VR) has also opened the path for the development of a fully interactive and immersive Metaverse (Bhatt, 2023).

2.2.1 The Evolution and History of Metaverse

Figure 2.2: Virtual worlds with avatars

Source: Boyd (2023)

Initially, the Metaverse manifested as a network of virtual worlds, allowing users to interact with each other and traverse between distinct virtual environments populated by other users in real time using avatars (Gilani, 2024) as shown in Figure 2.2. In the present era, the Metaverse includes social VR platforms that are seamlessly integrated with massive multiplayer online video games, expansive open-world settings, and collaborative AR environments. Furthermore, according to Bhatt (2023), it goes beyond singular platforms or applications, becoming an ecosystem of interconnected virtual realms and environments, where individuals interact and conduct transactions using digital assets like cryptocurrencies and NFTs.

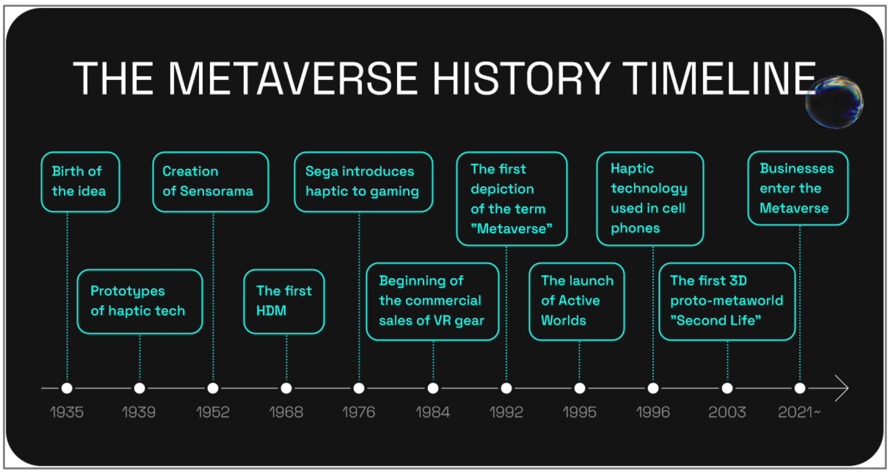


Figure 2.3 The Metaverse History Timeline

Source: Marć (2023)

The concept of the metaverse has its origins in science fiction, first being introduced by author Neal Stephenson in his 1992 novel "Snow Crash" (Lawton, 2024). In the early days, the idea of a shared, virtual digital world was explored through early virtual reality technologies and online virtual worlds like Habitat, Active Worlds, and Second Life in the 1980s and 1990s (Damer, 2008).

The rise of the internet, web 2.0, and social media platforms in the 2000s and 2010s further paved the way for increased online social interaction and the blending of digital and physical worlds. More recent advancements in virtual reality, augmented reality, and mixed reality hardware and software have reignited interest in the metaverse concept, making the vision of an immersive, interconnected metaverse more technically feasible. According to Drapkin (2023), companies like Facebook (now Meta), Microsoft, and Epic Games have invested heavily in developing immersive virtual spaces, social platforms, and gaming ecosystems, bringing the metaverse closer to reality.

Today, the metaverse is seen as a potential next frontier of the internet, offering limitless possibilities for social interaction, entertainment, commerce, education, and beyond. With ongoing technological advancements and growing interest from both industry and users, the metaverse is poised to continue evolving and expanding in the years to come, aiming to realize this long-envisioned concept of a unified, virtual digital realm.

2.2.2 Current Applications of Metaverse

In today's digital landscape, the metaverse stands as a transformative force reshaping numerous industries. From gaming to education, retail, business, art, and social interactions, its impact reverberates across diverse sectors, fundamentally altering the way we engage with technology and each other.

2.2.2.1 Gaming Industry

The integration of metaverse elements and augmented reality/virtual reality (AR/VR) technologies has long been a cornerstone of the gaming industry, continuously advancing to deliver visually stunning and immersive gaming experiences (Gupta, 2023). With ongoing enhancements in graphics and visuals, users are increasingly immersed in lifelike environments, fostering natural interaction with their virtual surroundings.

Figure 2.4: The Sandbox

Source: Ye (2022)

Companies like Decentraland, Sandbox, Epic Games, Meta (Facebook), Microsoft, Roblox, and Niantic are leading the charge, offering diverse career opportunities ranging from game design to blockchain development (Coursera, 2023). These companies are investing heavily in research and development to shape the future of metaverse gaming. Several popular metaverse games, including Alien Worlds, Axie Infinity, Chain of Alliance, Decentraland, Farmers World, Krystopia, Sandbox, and Pokemon Go, offer players unique experiences and opportunities to earn virtual assets (Coursera, 2023).

2.2.2.2 Education

The evolution of digital technologies has significantly impacted education, transitioning from traditional methods to more immersive and interactive experiences. While 2D technologies such as simulations, have been instrumental, they have limitations, particularly in engaging students and fostering social interaction (Clegg, 2023). The emergence of the metaverse, offers a transformative approach to learning across various disciplines, including anatomy, biology, geography, and chemistry, by providing a sense of presence and immersion. According to Clegg (2023), studies indicate that VR enhances comprehension, engagement, motivation, and knowledge retention of academic concepts, offering opportunities for experiential learning.

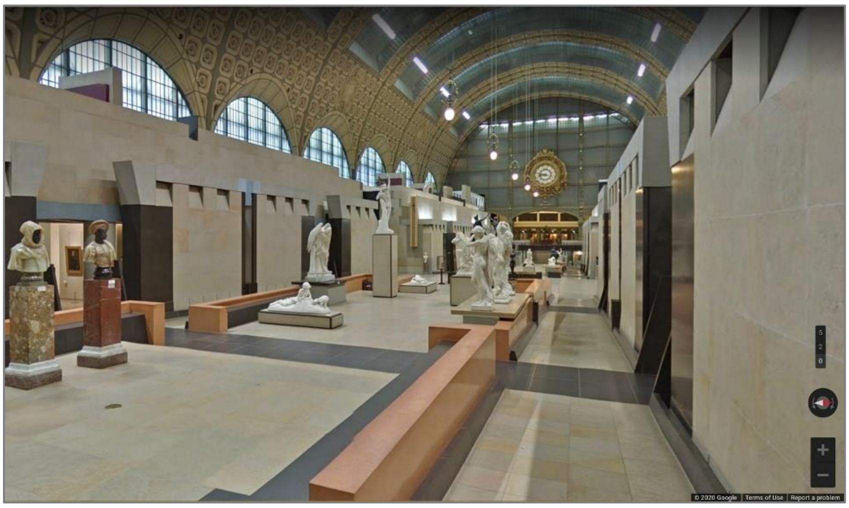


Figure 2.5: Google Art & Cultures App

Source: Reiner-Roth (2020)

Real-world examples, such as virtual classrooms in Japan and virtual labs at Morehouse College, demonstrate the efficacy of metaverse technologies in education (Clegg, 2023). Moreover, according to Gupta (2023), educational tools like Google Arts & Cultures as shown in Figure 2.4, offer students virtual 3D tours of renowned museums, interactive experiences at cultural events like ballet performances, and simulated travel experiences, without leaving the classroom. Such applications demonstrate the power of AR/VR in enriching educational experiences and broadening students' horizons beyond traditional learning methods.

2.2.2.3 Retail

The metaverse presents unprecedented opportunities for brand promotion, offering innovative ways to engage customers and elicit higher response rates. Retailers, for instance, can leverage immersive experiences through virtual reality (VR) booths, allowing customers to virtually try on clothing before making a purchase (Gupta, 2023). This not only enhances customer engagement but also boosts sales by providing a more interactive shopping experience.

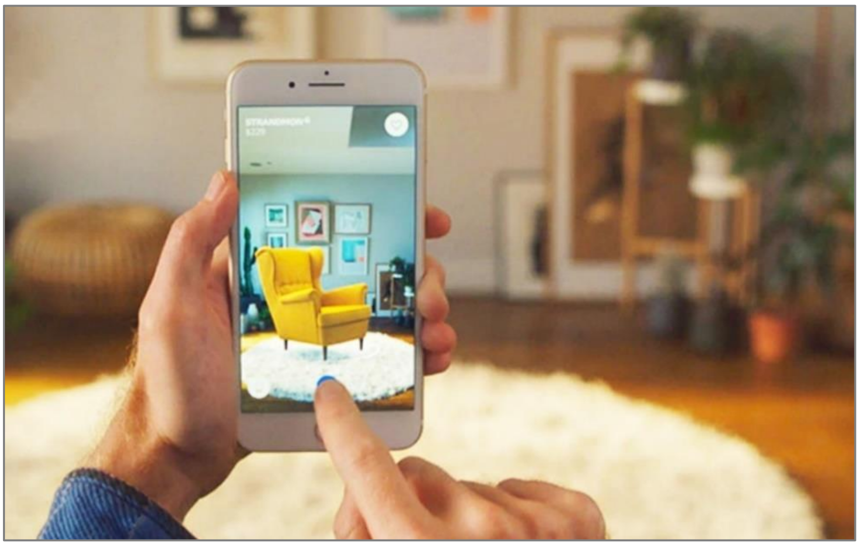


Figure 2.6: Ikea Place App

Source: Caroline (2022)

One notable example is Ikea, which employs marketing VR with its Ikea Place app, enabling customers to virtually place furniture in their own space to ensure proper size and fit as illustrated in Figure 2.5. By automatically scaling items based on room dimensions, Ikea enhances customer confidence in their purchasing decisions.

2.2.2.4 Art Industry

Furthermore, the metaverse is also reshaping the art world in multiple ways. It offers a platform for global interaction and exploration of virtual art galleries and museums, allowing individuals to engage with art regardless of their physical location (Masterworks, 2023). Through the use of non-fungible tokens (NFTs), the metaverse ensures secure transactions for buying and selling artwork, eliminating concerns about digital art replication (Masterworks, 2023).

Additionally, artists and buyers gain access to larger marketplaces, enabling the creation and exploration of virtual reality art galleries.

Figure 2.7: NFT Art Gallery

Source: Masterworks (2023)

Several platforms such as Decentraland, Cryptovoxels, Efinity, and Substrata By Epoch Gallery provide avenues for artists to showcase their work and for users to experience immersive virtual art exhibitions (Masterworks, 2023). According to Masterworks (2023), notable artists like Beeple, KAWS, Federico Clapis, Maylee Todd, Cassie McQuater, and Refik Anadol are leveraging the metaverse to exhibit their digital creations, from NFTs to virtual reality experiences. While metaverse art shows promise, investing in physical artworks remains a popular option due to its longer performance history and greater investment transparency.

2.2.2.5 Social and Work

The metaverse is poised to revolutionize remote work, offering enhanced social connections and collaboration through immersive platforms. These platforms aim to alleviate the isolation often associated with remote work by providing interactive virtual environments where employees can engage in meetings, presentations, and networking activities using digital avatars (Purdy, 2023). Additionally, metaverse companies such as PixelMax are focusing on solutions to combat video meeting fatigue and enhance team cohesion through features like spontaneous interactions, well-being spaces, and live status tracking within virtual workplaces (Purdy, 2023). Furthermore, according to Purdy (2023), advancements in AI-powered digital humans are paving the way for more personalized and interactive experiences, from AI assistants aiding in training and skills development to lifelike avatars facilitating realistic role-play simulations.

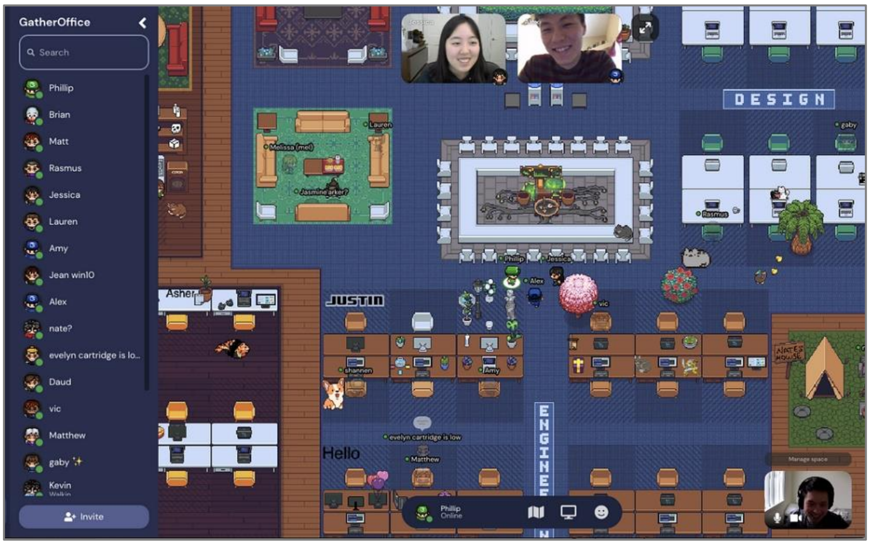


Figure 2.8: The Gather.Town App

Source: Sequoia (2022)

A famous social interaction platform, Gather (as shown in Figure 2.7), is redefining online social interaction by offering a versatile platform that seamlessly integrates work, community, and recreation (Sequoia, 2022). With its unique blend of virtual events, gaming, and video conferencing capabilities, Gather transcends traditional categorizations, creating a new space for connection. Users can design custom 2D spaces to host various activities, from large-scale conferences to intimate gatherings, fostering a sense of place and belonging (Sequoia, 2022). Founded by a team of young visionaries, Gather is rapidly expanding its user base and shaping the future of the metaverse by prioritizing authentic experiences and community building.

2.2.3 The Future of Metaverse

The investment in Metaverse technologies is on the rise, indicating a growing recognition of its transformative potential across diverse industries (Talin, 2023). By seamlessly merging physical and digital realms, the Metaverse blurs the traditional boundaries and redefining how people interact, communicate, work, play, and collaborate in virtual environments, offering unprecedented opportunities for collaboration, entertainment, education, business, and creative expression (Gilani, 2024). Imagine people attending virtual concerts, perusing virtual fashion boutiques, or even participating in virtual classrooms.

Moreover, by allowing secure ownership and exchange of digital assets, it has the potential to create completely new markets and businesses (Bhatt, 2023). For example, virtual real estate may develop as a valuable commodity in the Metaverse, where users purchase and sell virtual property in a manner similar to real-world transactions (Bhatt, 2023).

The Metaverse is still in its early stages of development, with low adoption rates due to a number of issues including insufficient processing power, poor user experiences, expensive hardware, and technical limitations that prevent multiple users from interacting at once. However, these challenges merely scratch the surface of the vast potential that the Metaverse holds. Overcoming significant technological hurdles, including content moderation and security concerns surrounding identity protection, is critical to instil user trust and confidence in the Metaverse ecosystem (Talin, 2023).

2.3 Mixed Reality Technology

Figure 2.9: A man experiencing mixed reality technology.

Source: Billinghurst (2017)

Mixed reality (MR) technology blends elements of both augmented reality (AR) and virtual reality (VR), creating immersive environments where digital and physical objects coexist and interact in real-time (Aloqaily et al., 2023). Mixed reality technology includes its ability to merge physical and digital worlds, providing users with immersive and interactive experiences that bridge the gap between the virtual and real (Harrison, 2023). MR offers a spectrum of experiences, from simple overlays of digital content onto the physical environment to fully immersive simulations where virtual objects interact with real-world surfaces and objects.

2.3.1 Key Difference between AR, VR, and MR

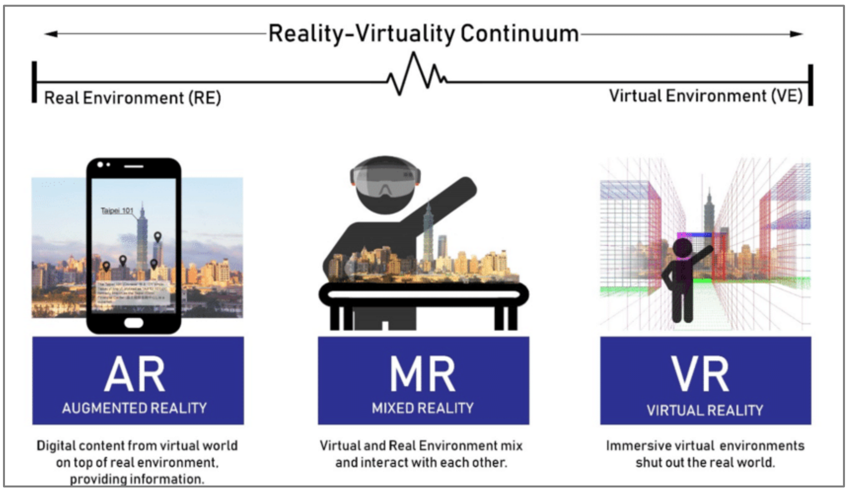


Figure 2.10: Differences between AR, MR, and VR

Source: Carrasco and Chen (2021)

The key difference between AR, VR, and MR lies in the level of immersion and interaction they offer. AR overlays digital content onto the physical world (Tremosa, 2024), allowing users to interact with virtual objects in their environment. VR immerses users entirely into a digital environment, cutting them off from the physical world (Tremosa, 2024). MR combines elements of both AR and VR, allowing virtual objects to interact with the real world and providing users with immersive experiences that blend digital and physical elements.

2.3.2 Mixed Reality Applications

Mixed reality technology lies in its potential to revolutionize various industries, including education, healthcare, manufacturing, and entertainment. In **education**, MR can create immersive learning environments that simulate real-life scenarios (Harrison, 2023), where students can explore complex concepts in science, engineering, and other subjects. In **healthcare**, MR can assist surgeons in planning and performing surgeries with greater precision and assist patients better comprehend their medical condition through 3D models (Harrison, 2023). In **manufacturing**, MR can streamline the design and prototyping process, allowing engineers to visualize and test products in virtual environments before they are built (Kaplan and Kaplan, 2024). In **entertainment**, MR can create immersive gaming experiences that blur the line between fantasy and reality.

2.3.3 Advantages, Challenges and Future Developments

Mixed reality (MR) offers **enhanced user engagement** through immersive experiences that maintain user interest over extended periods (Harrison, 2023). Unlike virtual reality (VR), MR seamlessly integrates virtual elements with the real world, making it ideal for tasks requiring situational awareness. According to Harrison (2023), MR serves as a **valuable tool for training and simulation** across diverse industries, providing a safe and cost-effective means of learning. Harrison (2023) also stated that MR's ability to **visualize complex data and models** in 3D enhances comprehension and facilitates better decision-making.

Moreover, MR promotes **collaboration** by allowing users to interact with digital content in a shared physical environment, fostering teamwork and innovation (Harrison, 2023).

Although mixed reality has a lot of potential, there are a number of limitations to overcome, such as the need for **better technology**, **concerns about privacy**, and **cost effectiveness**. We may anticipate MR being more widely available and incorporated into our daily lives as technology develops.

2.4 Constructivism Learning Theory

Constructivism is a learning theory that emphasizes the active role of learners in constructing their understanding of knowledge and reality through experiences and interactions with the environment. According to constructivism, learning is an active process where learners actively build their understanding by connecting new information and experiences with their existing knowledge and beliefs (Mcleod, 2024).

2.4.1 Importance and Advantages of Constructivism

The importance of constructivism lies in its **student-centered approach**, shifting the focus from the teacher as the sole source of knowledge to the learner as an active participant in the learning process (Serin, 2018). By engaging students in hands-on activities, problem-solving tasks, and real-world experiences, constructivism promotes deeper understanding and meaningful learning This approach fosters **critical thinking skills**, as students are encouraged to question, analyse, and establish own perspectives (Tprestianni, 2023). According to Saleem et al. (2021), **collaboration** and **social interaction** play a crucial role in constructivist learning environments, allowing students to learn from their peers and engage in meaningful discussion that is supervised and regulated by the teacher. As a result of social constructivism, learners' roles have shifted from passive listeners to active participants and co-constructors in information exchange among co-learners, transferring responsibility for knowledge acquisition from teachers to students (Saleem et al., 2021).

Constructivism’s advantages include increased student engagement and motivation, deeper understanding and retention of knowledge, development of transferable skills such as problem-solving and communication, cultivation of a disposition for lifelong learning, and the creation of authentic, meaningful learning experiences that connect classroom learning to real-world contexts.

2.4.2 Ways to Implement Constructivist Principles in Education

Constructivism education may be carried out through inquiry-based education, project-based education, problem-based education, cooperative education, scaffolding, and reflection:

1. **Inquiry-based learning**: This approach fosters curiosity and critical thinking skills by posing open-ended questions, problems, or scenarios that encourage students to actively explore concepts that spark their interest and participate in hands-on experiences (Learnenglishmk, 2023), leading them to construct their own understanding through research, hypotheses formulation, experimentation, and critical thinking.
2. **Project-based learning**: In project-based learning, students are given the opportunity to solve real-world problems that require them to use their knowledge and skills, fostering a paradigm in which these challenges help them grasp core subject concepts (Jumaat et al., 2017). Through active participation in authentic tasks and collaborative activities, students develop their decision-making, problem-solving, and constructive inquiry skills, which improve their engagement and comprehension of the subject matter (Jumaat et al., 2017).
3. **Problem-based learning**: In contrast to inquiry-based learning, problem-based education presents students with authentic, complex problems to solve (Tprestianni, 2023). Through this approach, learners actively construct knowledge by identifying relevant information, generating hypotheses, testing solutions, and reflecting on their learning process.
4. **Cooperative education**: Also known as collaborative learning, cooperative education involves students working together in small groups or one-on-one with another student to discuss an idea provided to them and come up with a solution (Tprestianni, 2023). By engaging in cooperative activities such as discussions, debates, peer teaching, or group projects, students construct meaning through interaction, negotiation, and shared experiences.
5. **Scaffolding**: Scaffolding refers to the support provided by teachers, peers, or learning resources to help students build on their existing knowledge and

skills. By constantly adjusting the level of support in response to learners' performance (Mcleod, 2024), scaffolding encourages them to take ownership of their learning and construct deeper understanding independently.

By fostering active participation, critical thinking, teamwork, and metacognitive awareness, these techniques help students have meaningful learning experiences.

2.5 Reviews on Similar Applications

Five similar applications will be reviewed on the following sections, including its advantages and disadvantages, along with detailed comparisons.

2.5.1 PhET Interactive Simulations

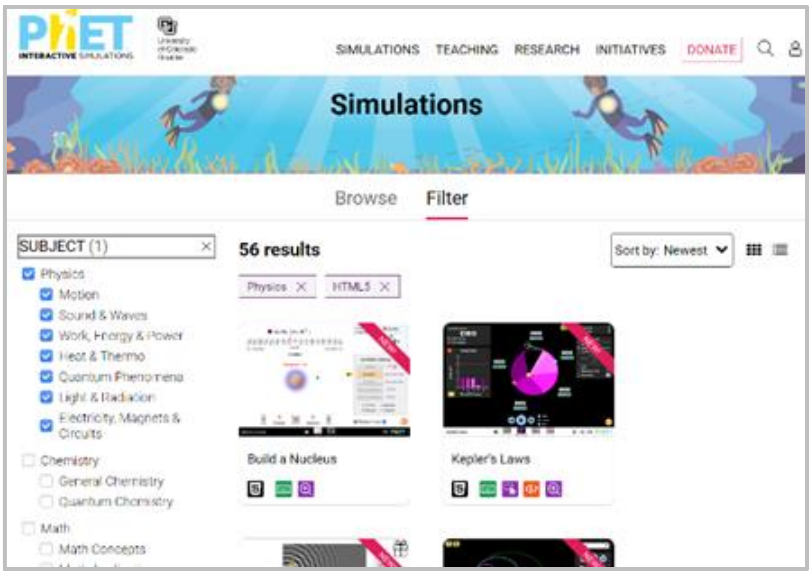


Figure 2.11: PhET Interactive Simulations Interface showing Various Topics

Source: PHET Interactive Simulations

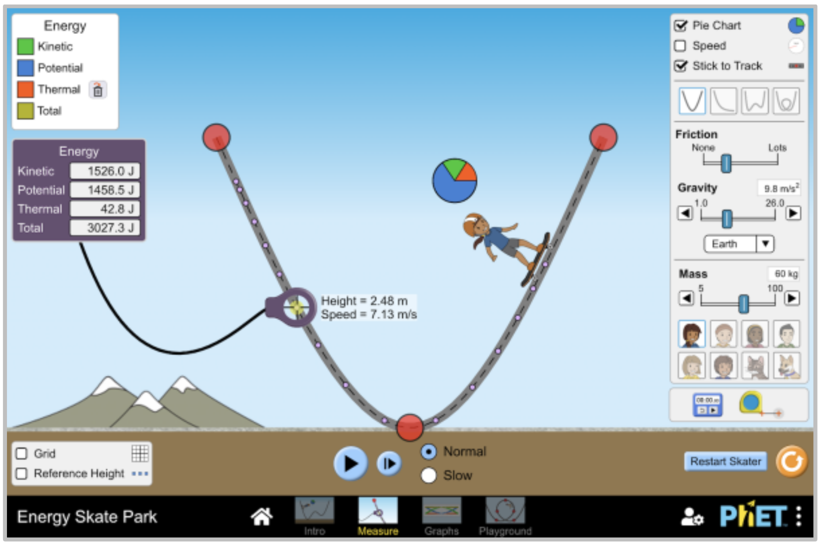


Figure 2.12: Experiments with various conditions

Source: PHET Interactive Simulations

PhET Interactive Simulations are a set of free, online interactive simulations created by the University of Colorado Boulder. These simulations are intended to assist students in learning and comprehending numerous concepts in Physics, chemistry, biology, earth science, and mathematics through interactive, game-like settings.

The PhET simulations are known for their user-friendly interfaces, intuitive controls, and visually appealing representations of scientific phenomena. They aim to engage students in an active learning process by allowing them to experiment with virtual models, manipulate objects, adjust parameters, and observe the resulting effects in real-time.

PhET simulations' strengths include **wide coverage of various Physics subjects**, **free accessibility online**, and **customisation options** that allow educators to tailor simulations with specific learning objectives. However, constraints such as being **limited to 2D visualisations**, the **lack of immersive experiences** provided by MR technology, and comparatively **limited interactivity** when compared to MR-based apps are significant flaws.

2.5.2 Labster

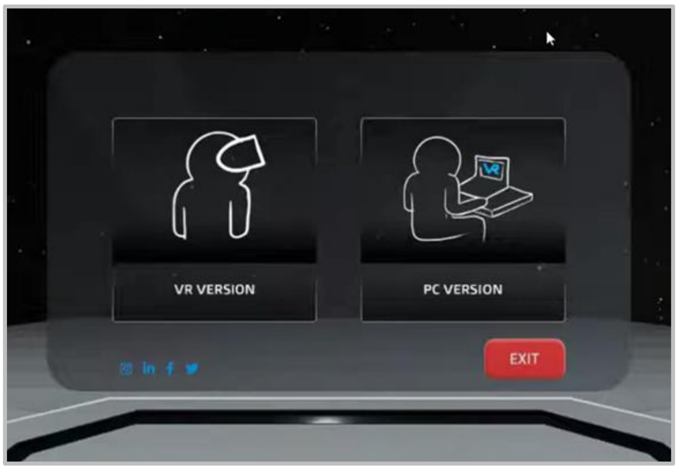


Figure 2.13: VR or PC Version Options

Source: Labster | Virtual labs for universities and high schools

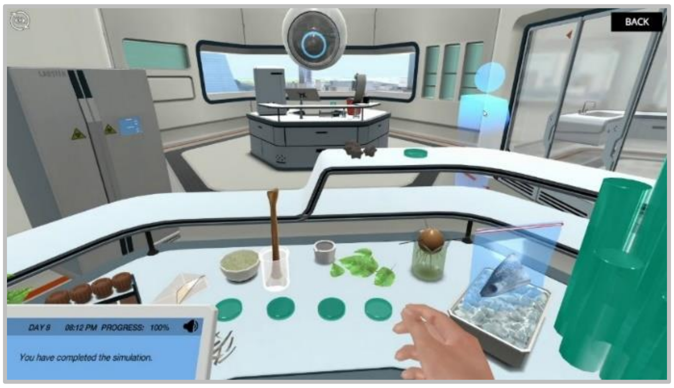


Figure 2.14: Immersive Virtual Hands-on Experiment

Source: Labster | Virtual labs for universities and high schools

Labster is a virtual reality (VR) platform that provides immersive laboratory simulations for science education, including Physics, chemistry, biology, and more. Labster simulations are designed to mimic real-world laboratory settings, complete with virtual lab equipment, instruments, and materials. Students can access the simulations via using VR headsets or desktop computers and perform experiments by following step-by-step instructions or exploring freely. The simulations include gamification elements, such as scoring systems and progress tracking, to enhance engagement and motivation. Additionally, Labster provides supplementary materials, including pre-lab and post-lab assignments, quizzes, and theoretical content to reinforce the learning experience.

Strengths of Labster include its provision of **virtual laboratory simulations** across various science subjects, **immersive 3D environments** facilitating realistic laboratory experiences, and a **safe and controlled**

environment for experimentation. Additionally, it enables **remote and collaborative learning**, integrates **gamification elements** to boost student engagement, and offers **personalized feedback mechanisms** to track student progress.

However, Labster has certain limitations. Its **subscription-based** or institutional access model may restrict accessibility for some users, while the **requirement for VR hardware and internet connectivity** can pose financial barriers. Moreover, the virtual lab experiences **lack the tactile elements** inherent in traditional laboratory work, and **customization options** for experiments and scenarios are comparatively limited compared to custom MR applications.

2.5.3 Pocket Physics

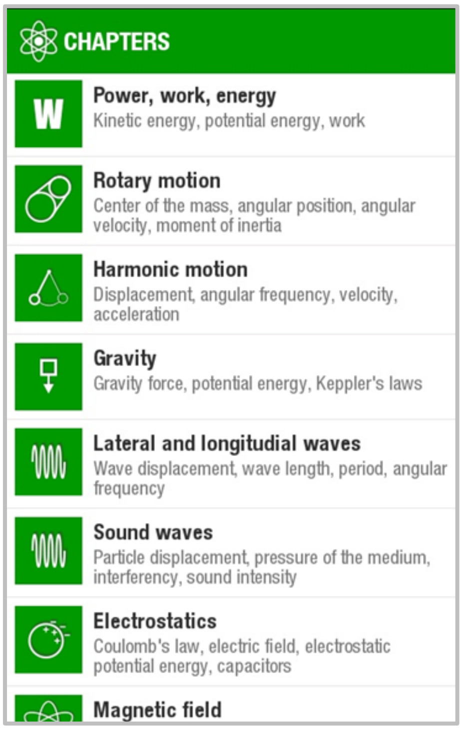


Figure 2.15: Various Topics in Pocket Physics

Source: Pocket Physics

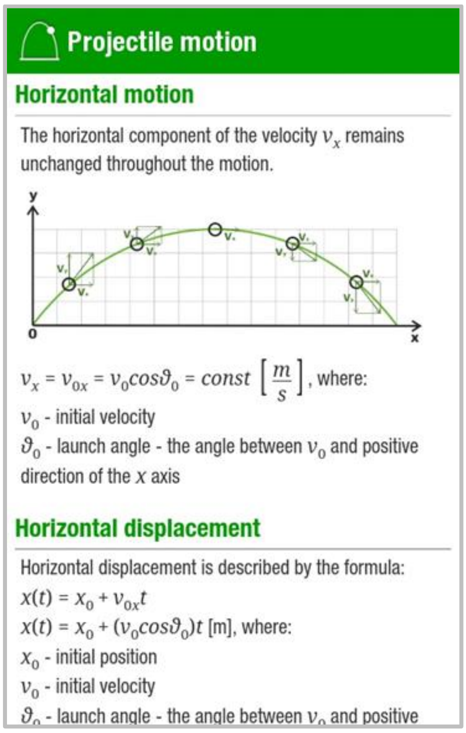


Figure 2.16: Explanation of a Physics Concept

Source: Pocket Physics

Pocket Physics is a user-friendly, no-cost educational app that encompasses essential Physics concepts, equations, and formulas. Whether you're seeking to review your understanding, study for exams, or simply revisit fundamental Physics principles, this app serves as an indispensable companion. With concise explanations spanning from linear motion to astronomy, Pocket Physics is an invaluable resource for those navigating introductory Physics courses. Additionally, it serves as a comprehensive reference, packed with formulas, equations, and visuals, ideal for students seeking assistance with Physics homework assignments.

The app boasts several strengths, including its coverage of a **wide range of topics**, **availability on mobile devices** for convenient on-the-go learning, and its utility as a **reference tool** for quick access to formulas and explanations. However, it does have some limitations, which include the **lack of in-depth explanations or discussions** on each concept, the **absence of customization options** to tailor the learning experience, and the **reliance on text-based explanations** rather than immersive 3D graphical representations. Additionally, Pocket Physics **does not provide engaging experiments**, which may limit its appeal to some users seeking hands-on learning experiences.

2.5.4 Microsoft HoloLens

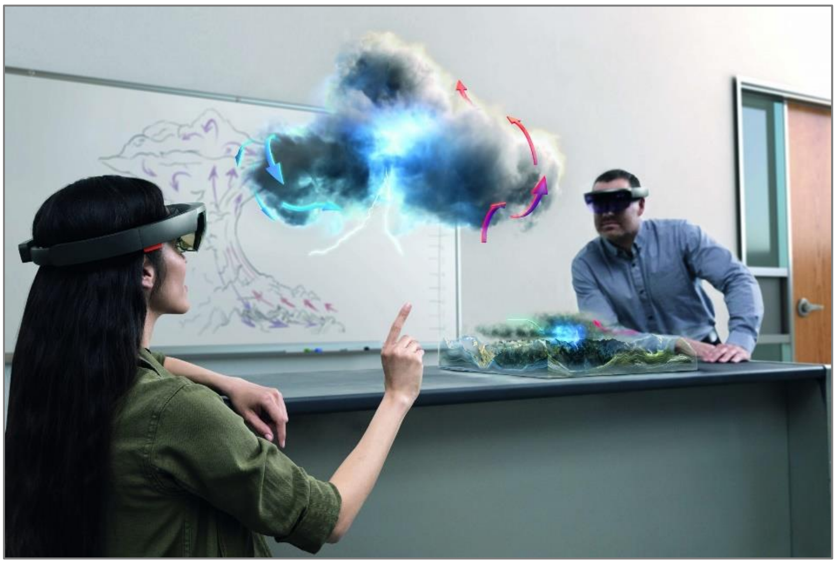


Figure 2.17: Using HoloLens in Education

Source: Bourne (2020)

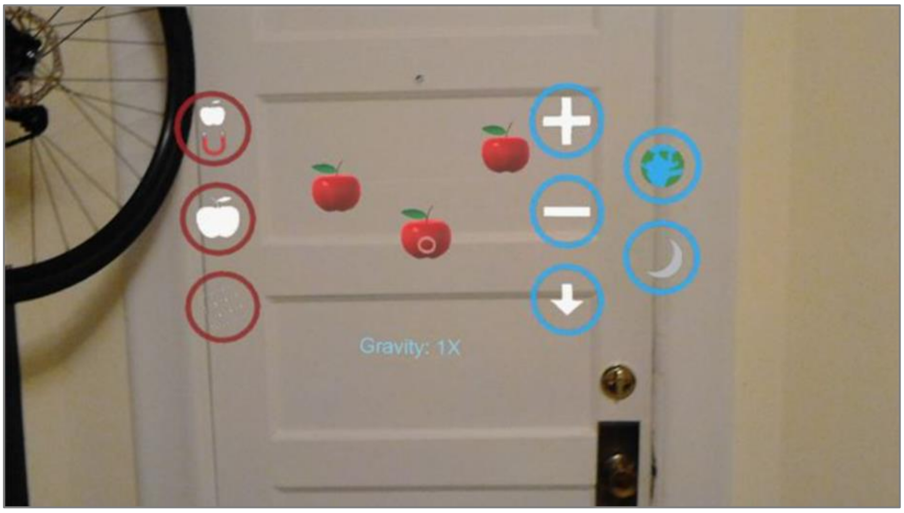


Figure 2.18: Demonstration of the Effects of Different Gravity via Microsoft HoloLens

Source: Newtons Apple - Microsoft Store

Microsoft HoloLens offers immersive augmented reality experiences that can revolutionize Physics education by enabling students to visualize abstract concepts and interact with virtual models overlaid onto the real world. With HoloLens, students can manipulate these holographic models, conduct virtual experiments, and visualize abstract phenomena in a hands-on manner. Additionally, HoloLens application like "Newtons Apple" (as shown in Figure 2.9) offer specific tools and simulations designed for Physics education especially in gravitation topic, allowing students to engage with Physics concepts in innovative and engaging ways.

Among its advantages, Microsoft HoloLens provides **immersive 3D holographic** experiences that seamlessly integrate digital content with the physical environment, as well as **collaboration and communication tools** for students and teachers. The platform gives users access to a variety of educational tools and materials, including Physics **simulations**, while also encouraging **hybrid teaching and learning methods** that speed up student progress and **personalise learning experiences**. However, HoloLens has significant restrictions, such as the **need for specialised hardware** (HoloLens), which can be expensive and may limit access for some users. Furthermore, the platform may have **fewer Physics-specific content** options than other educational platforms.

2.5.5 Moon Phases AR

Figure.2.19: Moon Phases main page

Source: Moon Phases AR – App Store (2018)

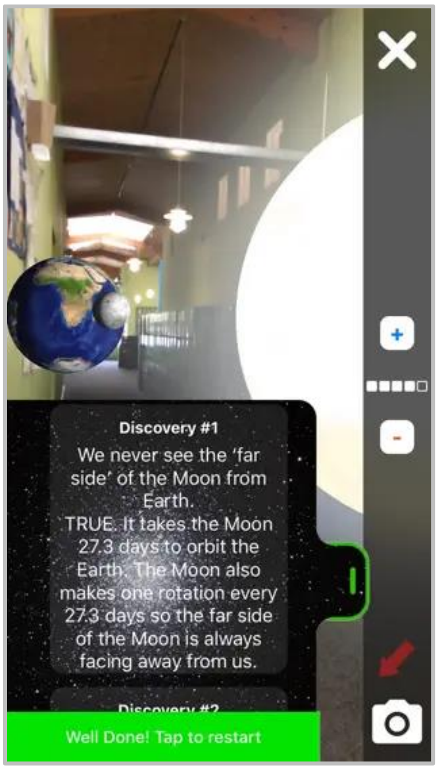


Figure 2.20: Explanation through AR

Source: Moon Phases AR – App Store (2018)

Figure 2.21: Outdoor Scale View

Source: Moon Phases AR – App Store (2018)

Moon Phases mobile applications utilise AR to allow for overlaying virtual representations of the moon's phases onto the real-world environment, illustrating the different phases of the Moon as it orbits around the Earth. Users can explore the lunar cycle, view the Moon's appearance on specific dates, and learn about the underlying scientific principles that govern the Moon's phases. This app consists of two views which are the indoor discovery view and outdoor scale view. It also includes additional features such as moon phase calendars, moon rise/set times, and educational content explaining the causes of the Moon's changing appearance.

The lunar phase mobile app offers various strengths, including an **interactive and visual learning** strategy that improves comprehension and engagement. Its **wide availability** enables users to learn about the lunar phases at any time and from any location. Furthermore, the **incorporation of supplementary information**, articles, and explanations improves the learning experience by giving users with a thorough understanding. Furthermore, the **use of real-time astronomical data ensures** the correctness of information on the Moon's current phase and position.

However, the application has its share of weaknesses. It may **not provide the depth and complexity** required for advanced astronomy education, limiting its usefulness to more advanced users. Furthermore, the **lack of hands-on experience** limits its capacity to replicate the authentic experience of observing the Moon directly in the night sky. Potential distractions within the app may lead users to perceive it as **a novelty or game** rather than an educational tool, potentially diminishing its educational value if not used intentionally for learning purposes. Furthermore, the **quality and performance** of the simulations are determined by the hardware specifications and capabilities of the user's mobile device, which may vary and impact the overall user experience.

2.6 Comparison of Similar Applications

(1 – Worst, 2 – Poor, 3 – Average, 4 – Good, 5 – Excellence)

Table 2.1: Media Elements of Similar Applications Comparison Table

No.	Name	Text	Images	Graphics	Audio	2D-Animation	3D-Animation	AR/VR
1	PhET Simulations	4	4	3	2	3	2	-
2	Labster	4	4	5	4	4	5	VR
3	Pocket Physics	3	2	2	1	1	1	-
4	Microsoft HoloLens	4	5	5	5	4	5	MR
5	Moon Phases	4	4	4	3	2	4	AR

Source: Compared by the author

Table 2.2: Interface Designs of Similar Applications Comparison Table

No.	Name	Usability	Intuitive Navigation	Clear Layout	Consistent Design	Interactive Elements	Clarity of Content	Error Handling	Appealing
1	PhET Simulations	4	3	4	3	4	3	3	3
2	Labster	5	5	5	4	5	4	4	5
3	Pocket Physics	3	2	4	3	2	3	3	3
4	Microsoft HoloLens	5	5	5	4	5	4	4	5
5	Moon Phases	4	4	4	3	3	3	3	3

Source: Compared by the author

Table 2.3: Software Specifications of Similar Applications Comparison Table

No.	Name	Free Usage	Accessibility	Compatibility	Performance	Customization	Updates
1	PhET Simulations	5	5	4	4	4	4
2	Labster	3	4	4	5	3	5
3	Pocket Physics	5	5	5	4	1	4
4	Microsoft HoloLens	1	3	4	5	5	4
5	Moon Phases	4	4	3	3	2	3

Source: Compared by the author

Table 2.4: Modules/Features Availability of Similar Applications Comparison Table

No.	Name	Physics Content	Conceptual Tutorial	Hands-on Experiment	Interactive Assessment	Gamification Element	Collaborative Learning
1	PhET Simulations	✓	✗	✓	✗	✗	✗
2	Labster	✓	✗	✓	✓	✓	✓
3	Pocket Physics	✓	✓	✗	✗	✗	✗
4	Microsoft HoloLens	✓	✗	✓	✗	✗	✗
5	Moon Phases	✓	✓	✗	✗	✗	✗

Source: Compared by the author

Table 2.5: Advantages and Disadvantages of Similar Applications Comparison Table

No.	Name		Content Coverage	Cost	Accessibility	Immersion	Interactivity
1	PhET	**Pros**	Broad coverage of Physics and STEM topics	Free and open-source	Free; available across multiple platforms (web, desktop, mobile)	Simple, visual simulations engaging for basic understanding	Highly interactive; customizable simulations
		Cons	Simplified models may not cover advanced Physics	None	Requires a good internet connection for full functionality	Lacks MR/VR; not fully immersive	Simplified models may lack depth
2	Labster	**Pros**	Deep focus on specific scientific areas with practical applications	High value for universities or professional environments	Available on multiple platforms	Full VR support for immersive lab experiences	Scenario-based, interactive virtual labs
		Cons	Limited coverage compared to broader platforms	Subscription; expensive for institutions	Requires high-performance hardware for VR	Expensive, requires VR headset for best experience	Limited outside structured scenarios
3	Pocket Physics	**Pros**	Covers essential Physics equations and concepts	Free mobile app	Lightweight, accessible on mobile devices	None	Simple interface for reviewing Physics formulas
		Cons	Limited to formulas and basic concepts without practical applications	None	Limited to mobile users	Lacks immersive or interactive elements like VR, AR, or dynamic simulations	Not interactive beyond static content

4	Newton's Apple (Microsoft HoloLens)	**Pros**	Highly immersive; strong focus on Newtonian mechanics	None	None	True MR with gesture and voice control for hands-free interaction; immersive and spatial understanding of Newton's laws	Hands-on, highly interactive with real-time object manipulation
		Cons	Focused only on Newtonian mechanics	Requires costly MR hardware	Limited access due to specialized requirement of expensive HoloLens headset;	None	Limited scope of interaction due to focus on one Physics law
5	Moon Phases	**Pros**	Visual and hands-on learning for specific astronomy concepts	Cost-effective; requires only a smartphone	Portable and accessible on smartphones	Immersive AR experience	Interactive AR visualization of moon phases
		Cons	Single topic focus (moon phases) limits broader learning	None	Limited to mobile users with AR-capable devices	No deeper immersive features like those in VR/MR apps	Limited interactivity beyond single topic

Source: Compared by the author

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Overview

The methodology adopted in software development refers to the systematic approach of planning, analysing, designing, building, testing, and deploying software solutions. Various methodologies are available for software development, each offering unique advantages and disadvantages. As depicted in Table 3.1, a comparative analysis of different methodologies used in software development illustrates their key characteristics. Given that the project encompasses instructional design, educational content development, and necessitates comprehensive evaluation, while also serving as an educational tool, the ADDIE model emerges as the most suitable methodology.

Table 3.1: Methodology Comparative Analysis

Methodology	**Agile**	**RAD** (Rapid Application Development)	**DevOps** (Development and Operation)	**ADDIE** (Analysis, Design, Development, Implementation, and Evaluation)
Approach	Iterative and incremental	Iterative and prototyping	Continuous integration and delivery	Structured and sequential

Primary Focus	Collaboration, flexibility, and rapid delivery	Rapid prototyping and quick development cycles	Collaboration between development and operations teams	Instructional design and development
Advantages	Flexibility & adaptability; Continuous improvement	Quick user feedback; Rapid development cycle	Automation and efficiency; Improved collaboration; Continuous improvement & innovation	Systematic approach; Emphasis on instructional design principle; Dedicated evaluation phase for quality assurance
Disadvantages	Lack of documentation; Potential for scope creep; Increased management overhead	Lack of documentation; Limited scalability; Depends on user feedback; Potential for incomplete requirement	Complexity; Potential for Over-Automation; Cultural resistance	Time consuming; Limited user involvement; Inflexible to change after initial phases
Suitable for	Projects with changing requirements, complex systems, and a focus on rapid delivery	Projects with well-understood requirements and a need for quick development	Projects with focus on continuous integration, delivery, and deployment	Projects involving instructional design, educational content development, and training programs

Source: Compared by the author

3.2 ADDIE Model

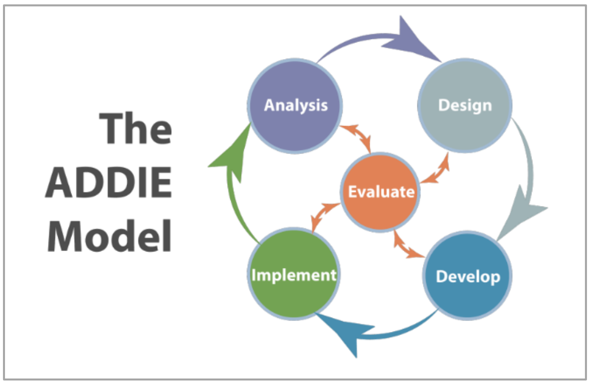


Figure 3.1: ADDIE Model

Source: Capytech Metaverse and E-Learning (2022)

The ADDIE model is a systematic instructional design model that provides a structured framework for developing effective educational materials, training programs, and instructional solutions (DeBell, 2020). ADDIE is an acronym that stands for the five phases of the model: Analysis, Design, Development, Implementation, and Evaluation.

3.2.1 Analysis Phase

During this phase, the instructional design team conducts a comprehensive analysis to pinpoint the learning requirements, target audience, instructional objectives, and constraints. This involves gathering information on the learners' attributes, existing knowledge, learning environment, and any pertinent organizational or situational factors. The analysis phase serves to define the instructional challenges and establish the foundation for subsequent phases.

In this project's analysis phase, the author outlined the problems and set out the project's objectives to ensure that the software addresses identified gaps and aligns with the audience's needs. Additionally, the project's scope, including its application modules, was defined. The target audience along with their characteristics, was also identified. Moreover, in-depth research of similar applications was conducted to identify their strengths and weaknesses in terms of user interface, media elements, and software specifications.

3.2.2 Design Phase

Based on the insights gathered during the analysis phase, the design phase shifts focus towards creating a comprehensive blueprint for the instructional solution.

This involves developing clear learning objectives, identifying suitable instructional strategies, designing assessments, and structuring the overall structure and flow of the instructional material. Designers may employ various techniques such as storyboarding, prototyping, or creating mockups to conceptualize the proposed solution, seeking input and validation from relevant stakeholders.

Within the design phase of this project, the author plans the instructional content's flow, ensuring coherence and effectiveness. Storyboards are created to map out the system flow and visualize the user interface and experience for the application, aligning closely with the project's scope. These storyboards serve as a visual representation to demonstrate how users will interact with the software. Additionally, low-fidelity prototypes are developed based on the storyboards, providing stakeholders with a better visualization of the software's design and functionality, facilitating feedback and iteration.

3.2.3 Development Phase

During this phase, the focus shifts to the actual creation of instructional materials, resources, and media in alignment with the design specifications outlined in the previous phase. This encompasses a range of activities such as producing multimedia content, developing interactive modules, authoring e-learning courses, and creating printed materials. Additionally, rigorous testing is conducted to identify and rectify any bugs or issues before proceeding to the implementation phase.

In the development phase of this project, the software is systematically constructed, module by module, adhering closely to the project's scope and incorporating feedback gathered through survey questionnaires. Each module is broken down into submodules, allowing for efficient and timely development. Visual elements, including 2D and 3D animations, as well immersive environments (VR, AR, and MR), are carefully designed and integrated into the software to enhance its visual appeal and functionality. Subsequently, the submodules are seamlessly integrated into a cohesive system, with each component undergoing rigorous testing both individually and as part of the integrated whole, to ensure robustness and effectiveness of the software before it advances to the next phase of implementation.

3.2.4 Implementation Phase

During the implementation phase, the instructional solution is deployed and made accessible to the target audience, whether through conventional classroom settings, online learning platforms, or other delivery channels. This stage may include providing training sessions for instructors or facilitators to familiarize them with the new tools and methodologies incorporated into the instructional solution. Additionally, pilot testing of the instructional materials may be conducted to gauge their effectiveness and identify any areas for improvement. Learners are given adequate support and tools to help them transfer smoothly to their new learning environment.

In this project's implementation phase, detailed training procedures are developed for both facilitators and learners to familiarise them with the newly introduced tools, including the software and hardware components such as the spectacles. The author ensures that all necessary resources (equipment and tools) are in place and operational, facilitating a smooth and effective implementation process.

3.2.5 Evaluation Phase

The evaluation phase is an important step in determining the effectiveness and impact of the instructional solution. This includes both formative assessments conducted during the developmental stages to identify areas that require improvement, and summative evaluations conducted after deployment to assess learning objectives and overall success. To gain thorough insights into the performance of the instructional solution, evaluation data is collected using a variety of approaches, including assessments, surveys, observations, and interviews. This feedback is critical for guiding modifications and determining future iterations of the instructional design.

During the evaluation phase of this project, various processes and techniques were employed to assess the system's usability, effectiveness, and user satisfaction in enhancing learning performance. Standardized testing tools such as the System Usability Scale (SUS) and the Post-Study System Usability Questionnaire (PSSUQ) were used to gather quantitative feedback. Participants included representative users from the target audience (Physics learners and educators), and their input was collected through surveys and observations. For detailed analysis and findings, readers are encouraged to refer to Chapter 5.

3.3 System Requirements

The system requirements for this project outline the necessary hardware and software components to ensure optimal performance.

3.3.1 Hardware Requirements

Table 3.2: Hardware Requirements

Hardware	Minimum Requirement	Optimal Requirement
Operating System	Window 7	Window 10
Processor (CPU)	Intel Core i3 / AMD Ryzen 5 5600H	Intel Core i7 / AMD Ryzen 7 5800H
Memory (RAM)	8 GB	16 GB
Hard Drive (Storage)	512 GB	1TB
Graphic (GPU)	NVDIA GTX 1650	NVDIA RTX 3050

Source: Created by the author

3.3.2 Software Requirements

Table 3.3: Software Requirements

Multimedia Elements	Software	Description
Text	Notes, Microsoft Word	For scripting, and documentation
Graphic	Adobe Illustrator	To create and edit graphical object
Audio	Murf AI (TTS software)	To generate text-to-speech voice

Augmented Reality		Vuforia	To create AR environment
Virtual Reality		Unity 3D, Autodesk Maya	To create VR environment
Animation	2D	Adobe Animate	To create 2D animation
	3D	Blender	To create 3D objects and animation
Authoring Tool		Unity, Adobe Animate	To combine all multimedia

Source: Created by the author

3.4 Fact Findings

This project was developed based on a combination of primary and secondary data sources. Primary data was gathered through a detailed user requirements analysis, which included survey questionnaires aimed at understanding the needs and preferences of students and educators. This data collection helped to identify the current challenges in learning Physics, particularly the difficulty in visualizing abstract concepts, limitations of traditional educational tools, and the lack of engagement in conventional Physics education methods.

Secondary data was collected through comprehensive literature reviews, focusing on similar educational systems and the application of mixed reality (MR) technologies in learning. By reviewing the use of MR in various fields, the study was able to compare existing platforms and identify the shortcomings in current educational technologies. This led to the formulation of the problem statements, which highlighted the need for an immersive, engaging learning platform.

Both sets of data were crucial in shaping the objectives and the overall direction of the project. The primary data emphasized user preferences and expectations, while the secondary data offered insights into technological advancements and pedagogical approaches, allowing the project to integrate innovative solutions to address the key issues faced by Physics learners today.

3.5 User Requirement Gathering and Analysis

In this section, the author conducted a user requirement gathering and analysis to understand the needs and expectations of the target users for the learning application. A structured questionnaire was employed as the primary research tool to gather data from the intended user base.

3.5.1 Survey Questionnaire

Questionnaires are widely recognized for their ability to collect information systematically from a sample group, utilizing standardized questions to ensure consistency and reliability in the responses. There are various methods for administering questionnaires, including online surveys, interviews, and paper-based forms. In this project, the author conducted a comprehensive user learning application survey using a structured questionnaire to gather data from the target users and identify their preferences. Google Forms, an efficient and user-friendly platform is used for creating and distributing questionnaires. Google Forms allows for the creation of customized surveys that can be easily shared with a large audience. The questionnaire featured primarily closed-ended questions to streamline data analysis and ensure clarity in the responses.

The survey was carefully structured to accommodate various respondent categories, including Physics educators, learners, and individuals with or without prior experience in immersive technologies. It was divided into sections to cover key areas of interest. Section I & II covers demographic information to understand the background of participants. Section III explored the challenges faced by respondents, whether in learning or teaching Physics, or in using educational applications. Section IV delved into personal experiences with, or opinions about, immersive technologies, offering insights into how familiar or comfortable respondents were with these tools. Finally, Section V focused on gathering detailed feedback on specific requirements and preferences related to the learning application. The data gathered from the survey was automatically analysed and visualized using Google Forms' built-in tools – graphs and charts, providing valuable insights into participant preferences and needs. Appendix A provides screenshots of the Google Form questionnaire used in this process.

3.5.2 Data Collection and Analysis

3.5.2.1 Knowledge about Metaverse

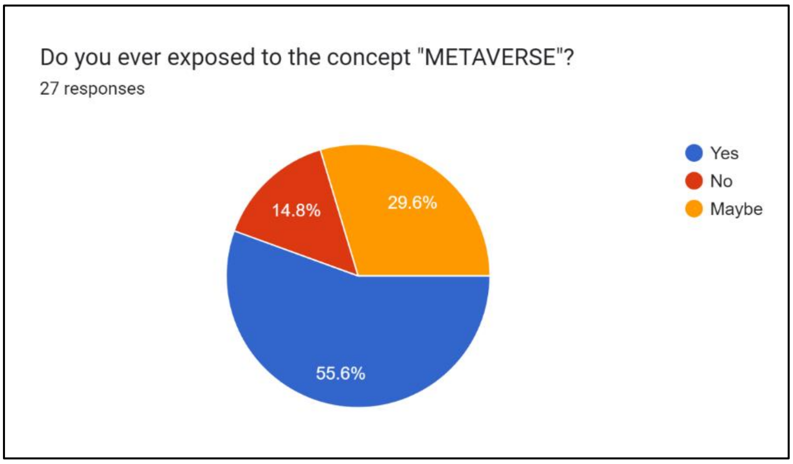


Figure 3.2: Pie chart of exposure towards metaverse question

The pie chart above shows the distribution of 27 responses across three categories. The majority of respondents (over half) indicated that they had been exposed to the concept of the metaverse, while a smaller portion were unsure, and the smallest group had not been exposed to the concept.

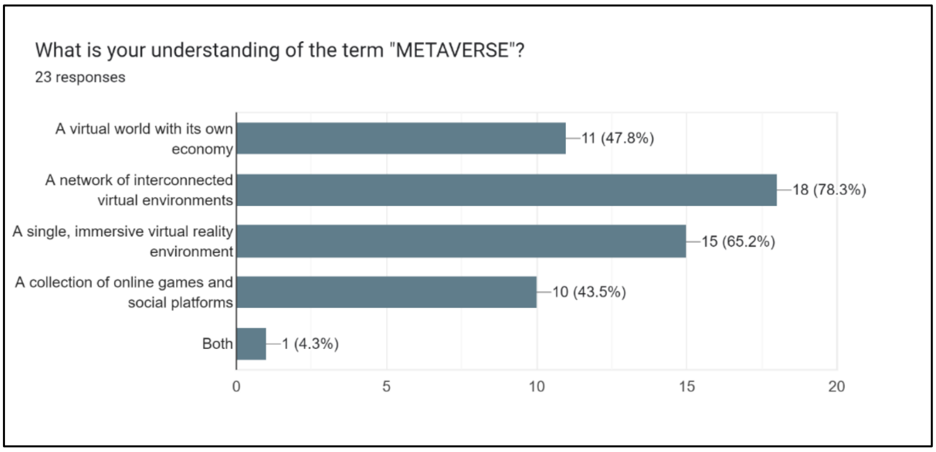


Figure 3.3: Bar chart of understanding of metaverse question

The bar chart above illustrates that illustrates responses to the question "What is your understanding of the term 'METAVERSE'?" based on 23 responses. Notably, respondents could select multiple options, as the percentages sum to over 100%. This indicates that many people associate the metaverse with multiple concepts, particularly viewing it as an interconnected network of virtual environments and an immersive VR experience.

3.5.2.2 Section I – Respondent's Type

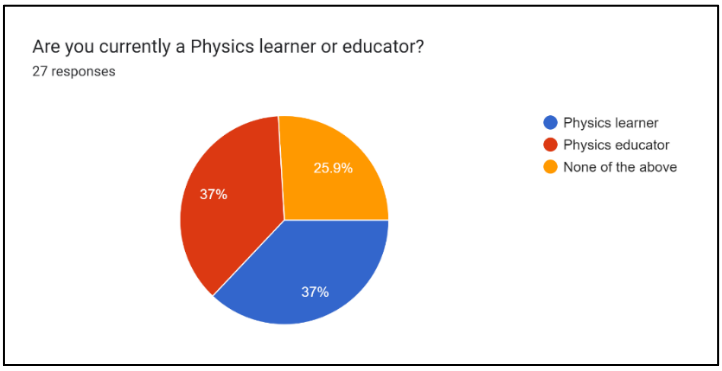


Figure 3.4: Pie chart of types of respondents

The pie chart above displays an even split between Physics learners and educators, each comprising 37% of the respondents. The remaining 25.9% of participants fall into neither category. This distribution suggests that among the survey participants, there's an equal representation of those learning and teaching Physics, with about a quarter of respondents not directly involved in Physics education or learning.

3.5.2.3 Section II – Demographic Information

Physics Learner

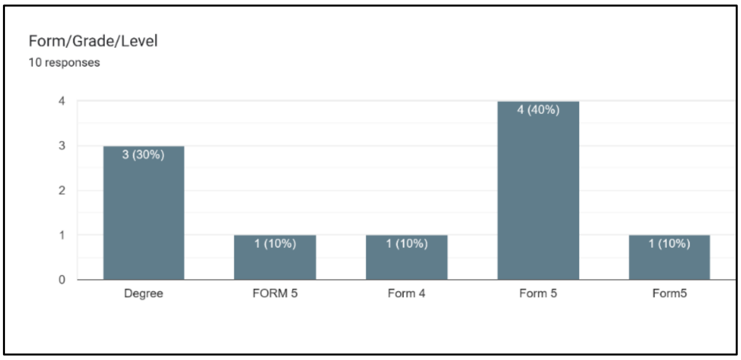


Figure 3.5: Column chart of Form/Grade/Level

The column chart above displays the distribution of respondents across different forms, grades, or levels of education, based on 10 responses to a question about "Form/Grade/Level". The most common level is Form 5, with 60% of responses. This column chart presents the distribution of 10 respondents across various educational levels or grades. The most prevalent category is Form 5, accounting for 60% of responses (6 participants). Following closely, 30% of respondents (3 individuals) are at the Degree level. The remaining 10% of respondents are Form 4 student.

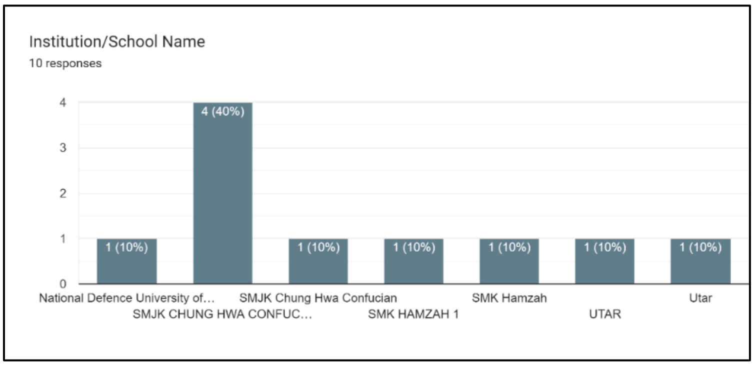


Figure 3.6: Column chart of Institution/School Name

This column chart displays the distribution of respondents across different educational institutions or schools, based on 10 responses. It provides an overview of the educational institutions represented in the survey, showing a concentration of respondents from SMJK Chung Hwa Confucian and a diverse representation from other institutions.

Physics Educator

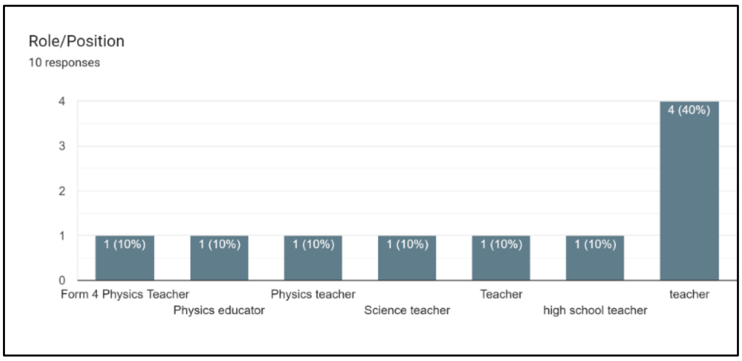


Figure 3.7: Column chart of Role/Position

The column chart above presents data on the roles or positions of 10 respondents, with the majority identifying as "teacher". This category includes various teaching roles, such as Physics, Science, and high school teachers.

Non-Physics Individual

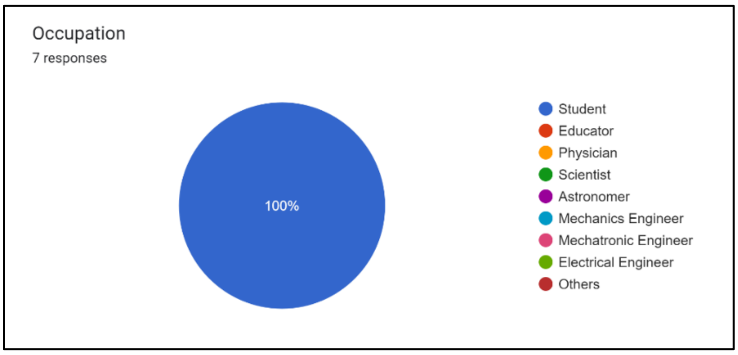


Figure 3.8: Pie chart of Occupation

The pie chart above illustrates the occupation distribution of the survey respondents, where all seven participants are students. This 100% student representation is significant as it indicates that the feedback gathered will be highly relevant for assessing the MetaPhysics learning application, specifically catering to the preferences and needs of its primary target audience — students. This helps ensure that the features and functionalities of the platform are aligned with the learning habits, challenges, and expectations of students, making the application more effective for educational purposes.

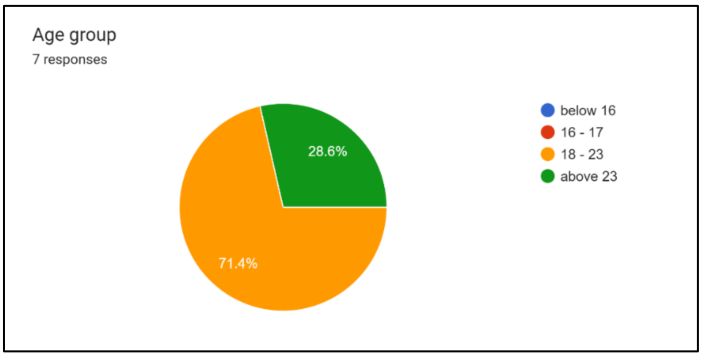


Figure 3.9: Pie chart of Age Group

The chart illustrated in Figure 2.29 shows the age group distribution of the seven respondents. A majority (71.4%) of participants fall within the 16-17 age group, while the remaining 28.6% are aged above 23. No responses were recorded for the below 16 or 18-23 categories. This distribution indicates that most of the respondents are likely high school students, which aligns with the target demographic for MetaPhysics. The feedback provided will therefore be valuable for tailoring the application to suit the needs of students in this age range, particularly in terms of content delivery and user engagement.

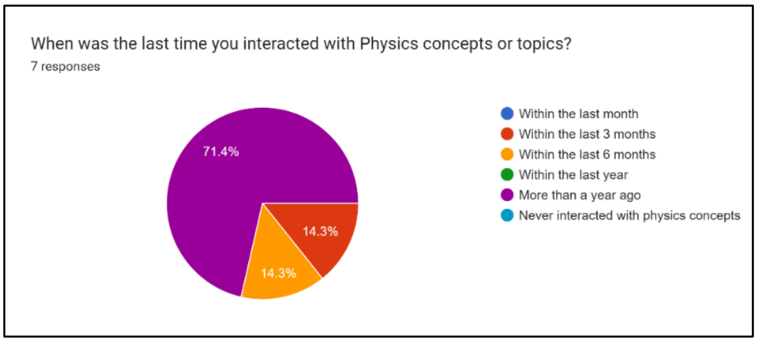


Figure 3.10: Pie chart of last interacted with Physics concept question

The pie chart above indicates that the majority (71.4%) of respondents last interacted with Physics concepts or topics more than a year ago. Meanwhile, 14.3% engaged with Physics concepts within the last 3 months, and another 14.3% within the last 6 months. None of the respondents interacted with Physics concepts in the last month or had no prior interaction with the subject. This suggests that most participants may have a gap in their recent engagement with Physics, which could be significant when evaluating the learning outcomes of the *MetaPhysics* application.

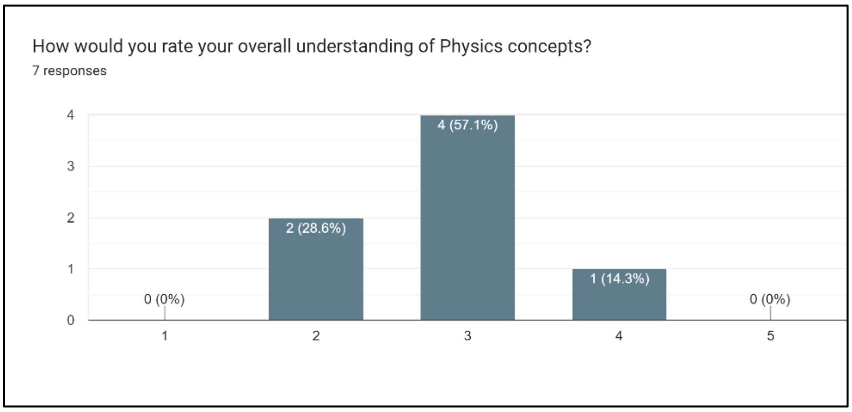


Figure 3.11: Column chart of rate of overall understanding of Physics

Figure 2.31 presents a column chart illustrating the responses from 7 participants. The responses were rated on a scale from 1 to 5, where 1 indicates the lowest understanding and 5 the highest. The majority of respondents (57.1%) rated their understanding as 3, indicating a moderate level of comprehension. Meanwhile, 28.6% selected 2, reflecting a below-average understanding, and 14.3% rated themselves at 4, showing a higher level of understanding. No respondents rated themselves as 1 or 5, showing that most participants fall in the mid-range.

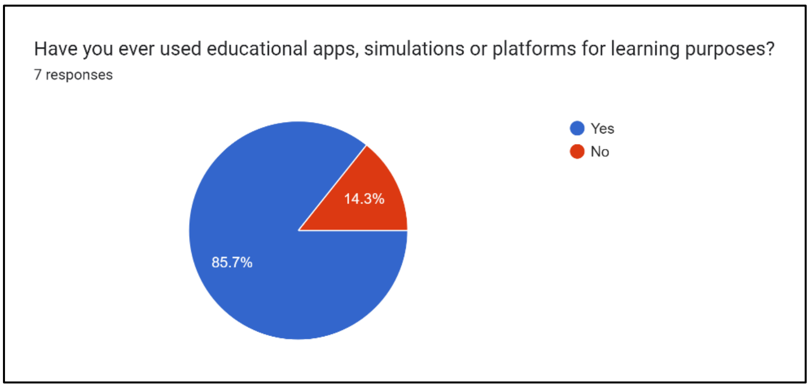


Figure 3.12: Pie chart of educational apps experience

The pie chart in Figure 2.32 illustrates the responses from a total of 7 participants. The majority, 85.7%, answered "Yes", indicating that most respondents have experience using educational technology for learning. A smaller portion, 14.3%, responded "No", signifying they have not used such tools. This suggests that most participants are familiar with technology-enhanced learning environments.

3.5.2.4 Section III (Learner) – Difficulty in Learning Physics

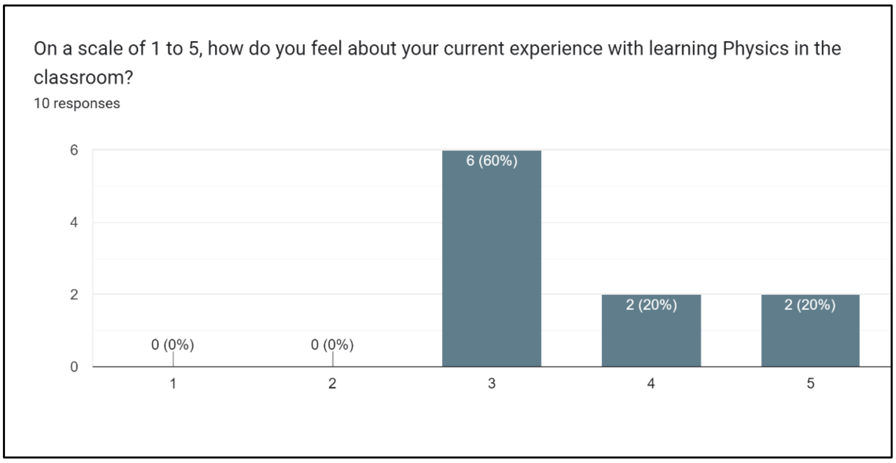


Figure 3.13:Column chart of respondent's current experience

The column chart illustrated in Figure 3.13 presents the responses to the question from 10 participants. The results show that 60% of respondents rated their experience as a 3, indicating a neutral or moderate level of satisfaction. Additionally, 20% rated their experience as a 4, and another 20% rated it as a 5, reflecting higher satisfaction levels. Overall, the chart suggests that while most participants find their experience average, a notable portion has a more positive outlook.

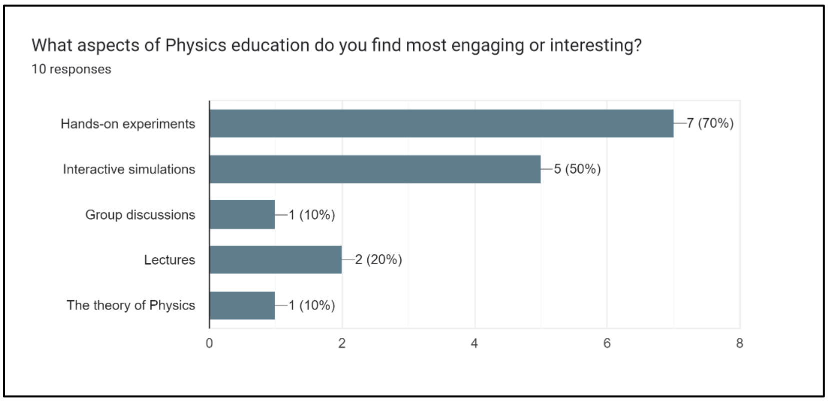


Figure 3.14: Bar chart of respondent's most engaging Physics education's aspect

The bar chart in Figure 3.14 illustrates participants' responses with 10 total responses. Hands-on experiments were the most popular, chosen by 70% of respondents, indicating a strong preference for practical, experiential learning. Interactive simulations were also favored by 50%, reflecting interest in technology-based learning tools. Other aspects like lectures (20%), group discussions (10%), and the theory of Physics (10%) were less popular, suggesting that students generally prefer more interactive and applied learning methods.

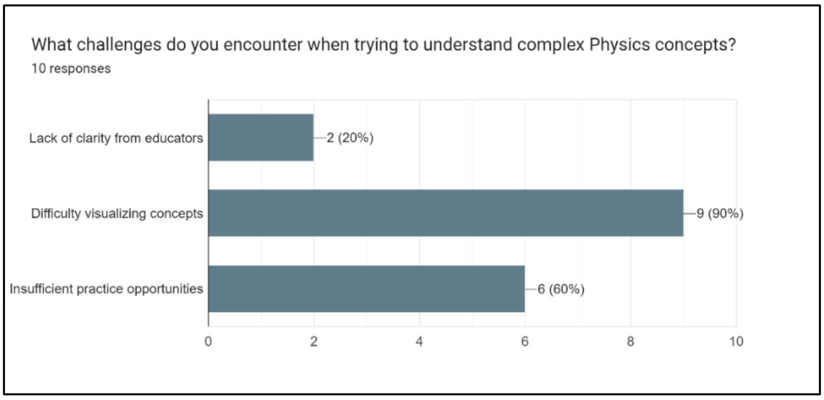


Figure 3.15: Bar chart of respondent's challenges encountered when learning Physics

In the bar chart shown in Figure 3.15, respondents were asked about the challenges they encounter when trying to understand complex Physics concepts. Out of the 10 responses, a significant 90% identified difficulty in visualizing concepts as a major issue. Additionally, 60% of respondents cited insufficient practice opportunities as a challenge. A smaller portion, 20%, pointed to a lack of clarity from educators as a concern. These results highlight the primary obstacles faced by learners in grasping complex Physics topics, emphasizing the need for improved visual aids and more interactive practice opportunities.

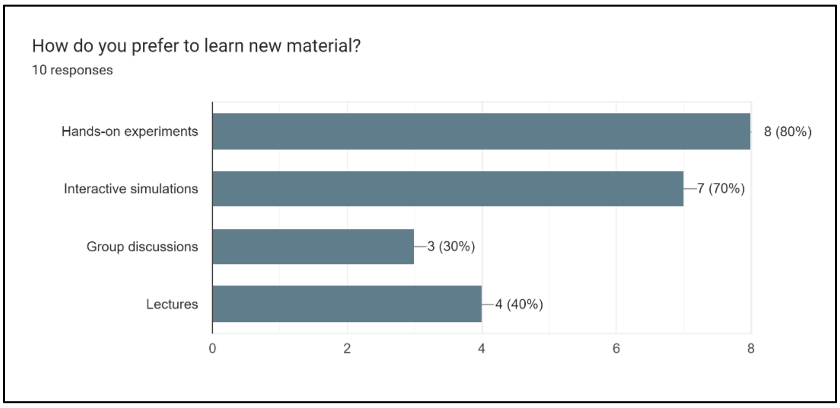


Figure 3.16: Bar chart of respondent's preferences to learn new material

Figure 3.16 presents a bar chart illustrating preferences for learning new material among 10 respondents. The chart reveals that 80% of participants favor hands-on experiments as their preferred learning method. Interactive simulations follow closely with 70%. Group discussions are less favored, with 30%, while lectures are preferred by 40% of respondents. This data highlights a strong inclination towards experiential and interactive learning methods over traditional lectures.

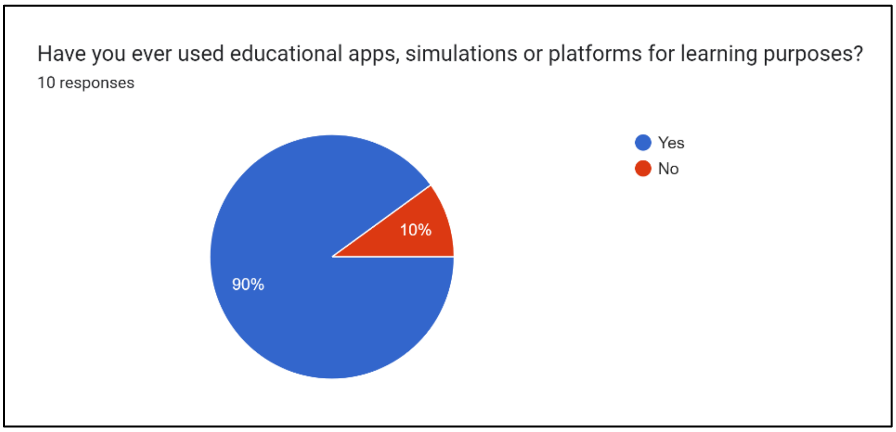


Figure 3.17: Pie chart of respondent's experiences in using education apps

Figure 3.17 is a pie chart showing responses to the question, "Have you ever used educational apps, simulations, or platforms for learning purposes?". Out of 10 respondents, 90% have used such tools, while 10% have not. This indicates a strong familiarity and usage of educational technology among the participants.

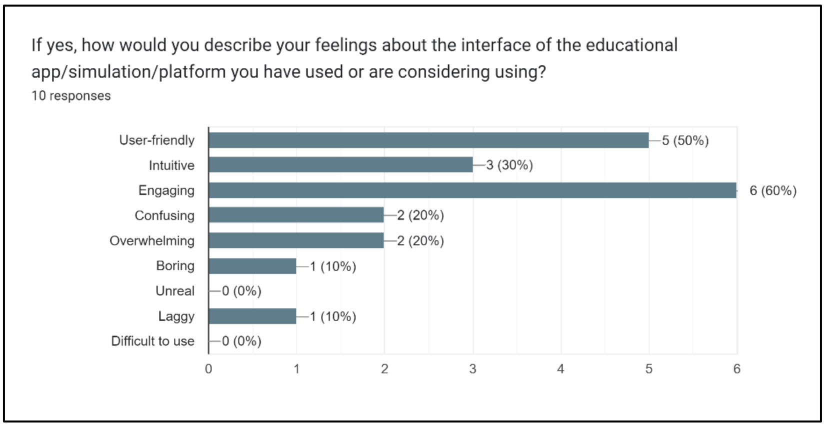


Figure 3.18: Bar chart of respondent's feeling about the interface of educational app used

Figure 3.18 is a bar chart depicting respondents' feelings about the interface of educational apps, simulations, or platforms they have used or are considering using. Among the 10 responses, 60% described the interface as engaging, 50% found it user-friendly, and 30% found it intuitive. However, 20% of respondents found the interface confusing or overwhelming, 10% found it boring or laggy, and no respondents reported it as unreal or difficult to use. This chart highlights that while most users have positive experiences, there are areas for improvement in terms of usability and engagement.

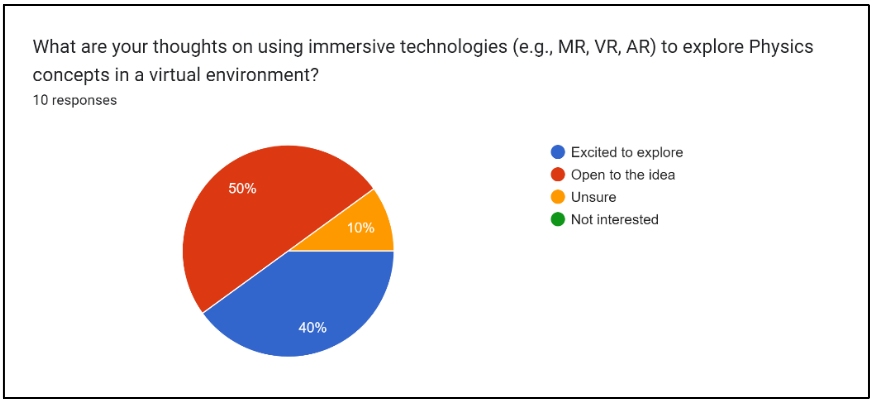


Figure 3.19: Pie chart of respondents' thoughts on using immersive technologies

Figure 3.19 shows a pie chart illustrating respondents' opinions on using immersive technologies (such as MR, VR, and AR) to explore Physics concepts in a virtual environment. Among the 10 respondents, 50% are open to the idea, and 40% are excited to explore these technologies. Only 10% are unsure about their potential, and none of the respondents expressed a lack of interest. This indicates a strong positive reception toward immersive technologies for learning Physics.

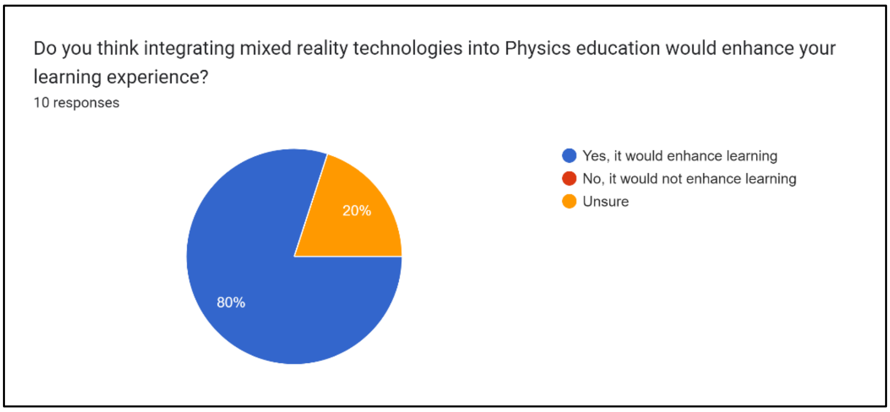


Figure 3.20: Pie chart of respondents' opinion on integrating MR technologies into Physics education

Figure 3.20 is a pie chart showing respondents' views on integrating mixed reality technologies into Physics education. The results indicate that 80% of respondents believe it would enhance their learning experience. None of the respondents think it would not enhance learning, and 20% are unsure. This suggests a strong consensus on the positive impact of mixed reality technologies in improving Physics education.

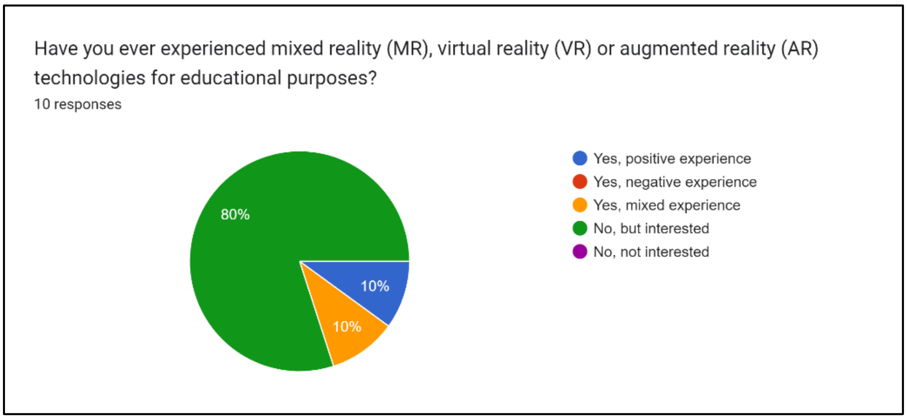


Figure 3.21: Pie chart of respondents' experiences with immersive technologies

Figure 3.21 illustrates a pie chart displaying respondents' experiences with mixed reality (MR), virtual reality (VR), or augmented reality (AR) technologies for educational purposes. The results show that 10% of respondents have had a positive experience, while another 10% had a mixed experience. None reported a negative experience or lack of interest, but 80% have not used these technologies yet but are interested in doing so. This indicates a strong interest in exploring MR, VR, and AR for educational purposes, despite limited current experience.

3.5.2.5 Section III (Educator) – Difficulty in Teaching Physics

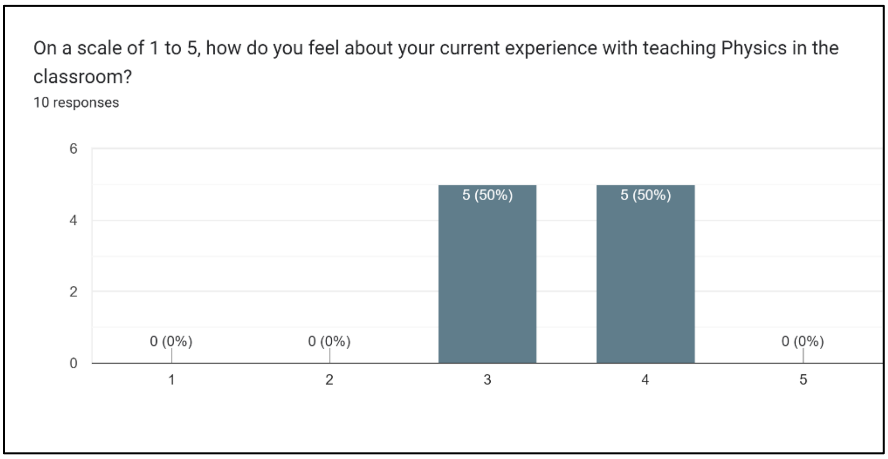


Figure 3.22: Column chart of respondents' ratings of their current experience with teaching Physics

Figure 3.22 is a column chart showing respondents' ratings of their current experience with teaching Physics in the classroom, using a scale of 1 to 5. The results reveal that 50% of respondents rated their experience as a 3, while the other 50% rated it as a 4. This indicates a generally positive but mixed sentiment about teaching Physics, with no extreme ratings at the lower or higher ends of the scale.

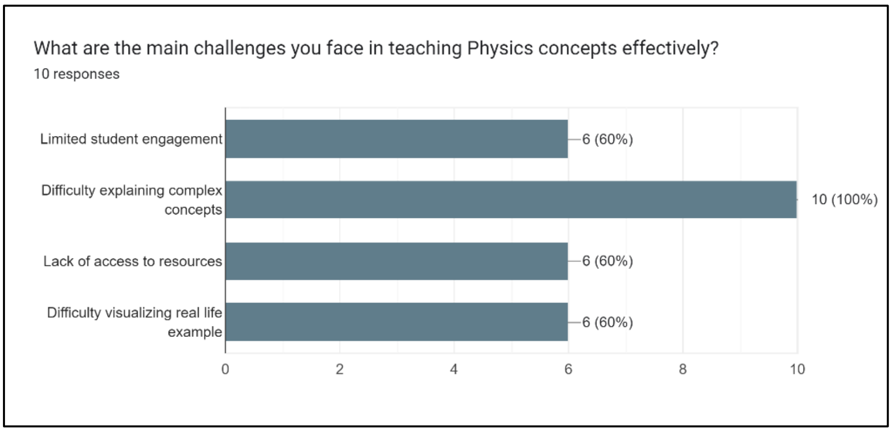


Figure 3.23: Bar chart of respondents' main challenges in teaching Physics concepts

Figure 3.23 is a bar chart depicting the main challenges faced in teaching Physics concepts effectively. The results indicate that 60% of respondents identified limited student engagement, lack of access to resources, and difficulty visualizing real-life examples as major challenges. Additionally, difficulty explaining complex concepts was noted by 10% of respondents. This suggests that engagement, resource availability, and practical visualization are significant hurdles in effective Physics teaching.

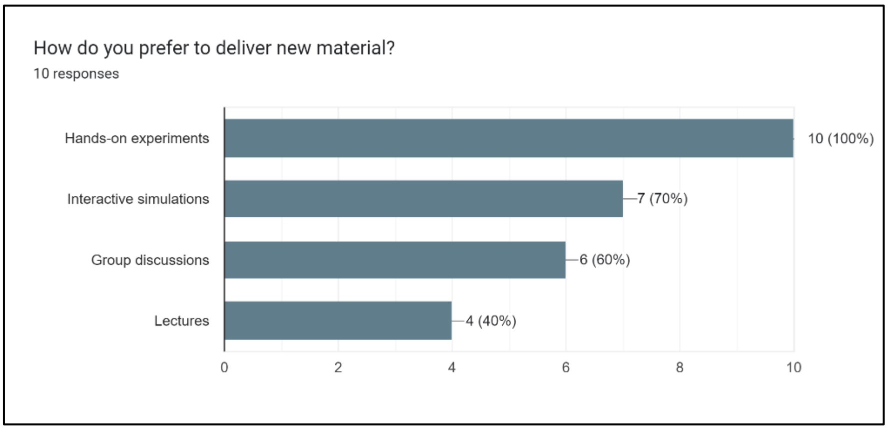


Figure 3.24: Bar chart of respondents' preferences to deliver new material

Figure 3.24 is a bar chart showing preferences for delivering new material. According to the results, 100% of respondents prefer hands-on experiments as their primary method for delivering new content. 70% favor interactive simulations, while 60% prefer group discussions. 40% of respondents choose lectures. This data highlights a strong preference for interactive and experiential learning methods over traditional lectures.

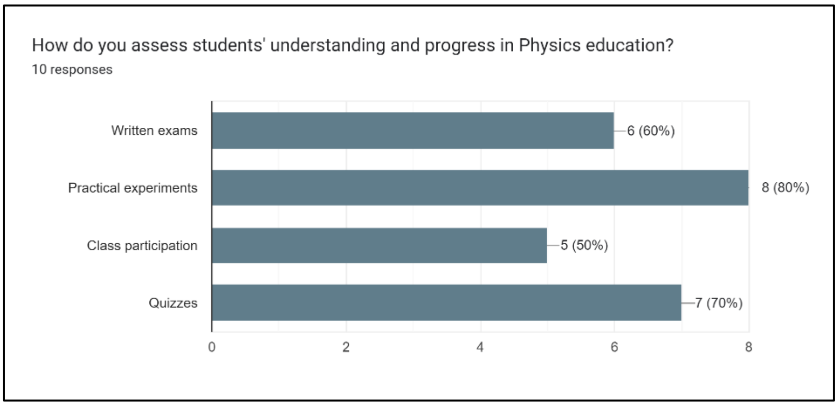


Figure 3.25: Bar chart of respondents' method to assess student's understanding

Figure 3.25 is a bar chart illustrating methods used to assess students' understanding and progress in Physics education. 80% of respondents use practical experiments as a key assessment tool, while 70% use quizzes. 60% rely on written exams, and 50% assess through class participation. This chart indicates a preference for hands-on and interactive methods, with practical experiments and quizzes being the most commonly used assessment approaches.

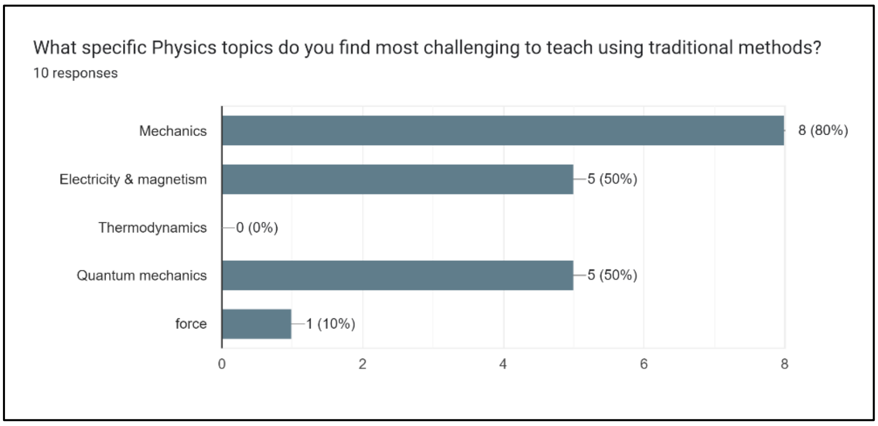


Figure 3.26: Bar chart of most challenging Physics topics to teach

Figure 3.26 is a bar chart depicting which specific Physics topics are considered most challenging to teach using traditional methods. 80% of respondents find Mechanics the most difficult to teach. Since the Force and Motion topic falls under Mechanics, this indicates that this topic is also notably challenging. 50% of respondents report difficulties with Electricity & Magnetism and Quantum Mechanics, while 10% find Force challenging. 0% identify Thermodynamics as a significant difficulty. This chart underscores Mechanics, including the Force and Motion topic, as the primary area of concern for traditional teaching methods.

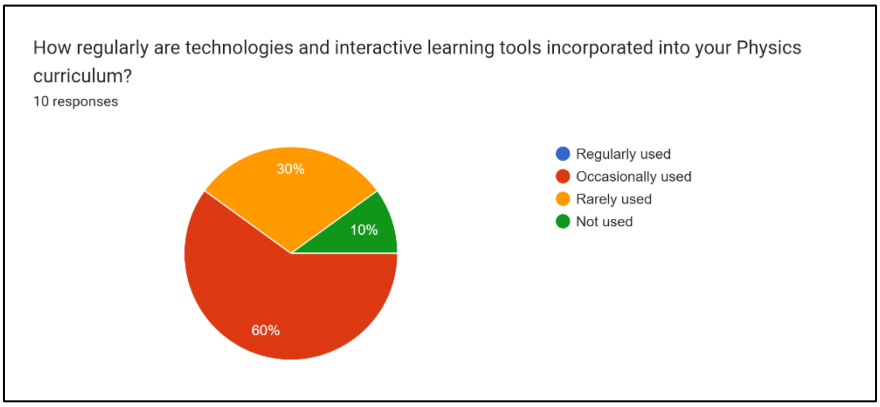


Figure 3.27: Pie chart of frequency with which tools are incorporated into Physics curriculum

Figure 3.27 is a pie chart showing the frequency with which technologies and interactive learning tools are incorporated into the Physics curriculum. 60% of respondents use these tools occasionally, 30% use them rarely, and 10% do not use them at all. None of the respondents reported using these tools regularly. This chart indicates a general trend towards infrequent use of interactive technologies in the Physics curriculum.

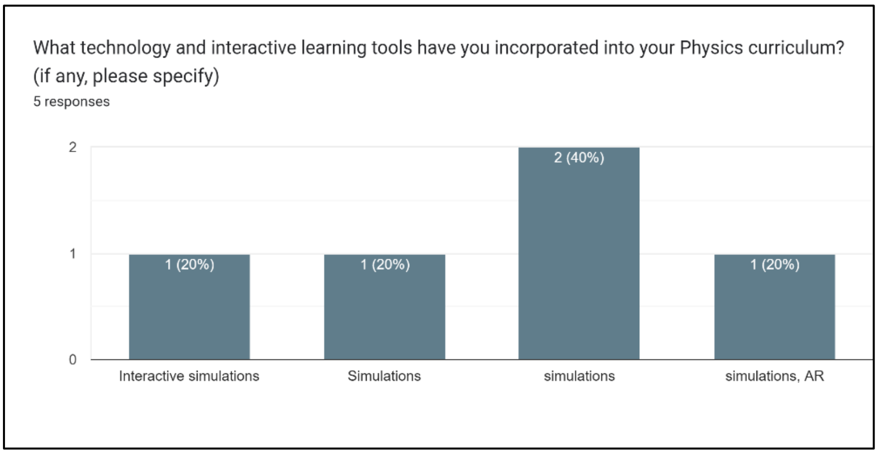


Figure 3.28: Column chart of types of technology used by respondents

Figure 3.28 presents a column chart showing the types of technology and interactive learning tools incorporated into Physics curricula. Among the 5 respondents, 60% use simulations, which may include interactive elements. 20% use interactive simulations alone, while another 20% combine simulations with Augmented Reality (AR). This distribution indicates that simulations are the most frequently employed tool, with a notable portion also integrating AR to enhance the learning experience.

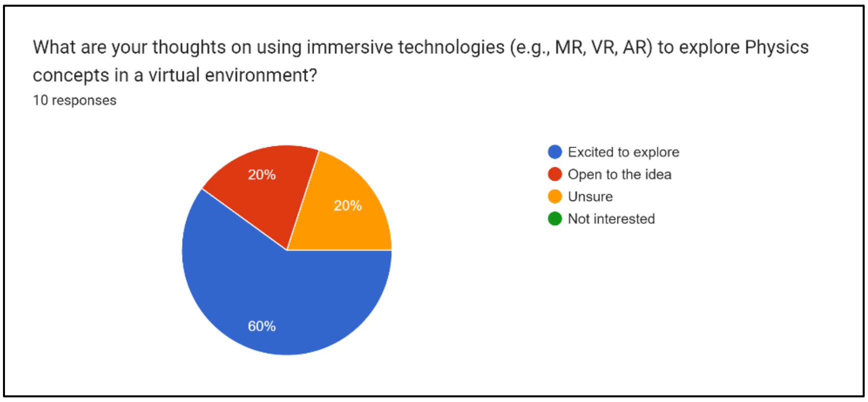


Figure 3.29: Pie chart of respondents' thoughts on using immersive technologies

Figure 3.29 displays a pie chart that captures respondents' attitudes toward using immersive technologies like MR, VR, and AR to explore Physics concepts in a virtual environment. Among the 10 respondents, 60% are excited to explore these technologies, suggesting a strong interest in their potential. 20% are open to the idea, indicating a willingness to consider these tools. Another 20% are unsure, reflecting some hesitation or uncertainty. Notably, 0% are not interested, which highlights a generally positive or open outlook towards integrating immersive technologies in Physics education.

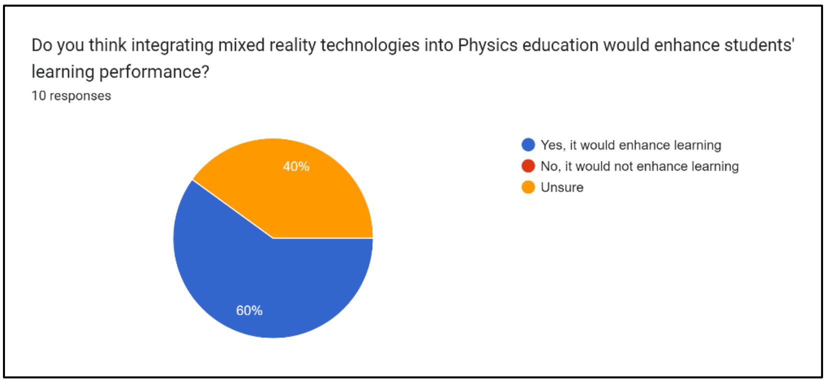


Figure 3.30: Pie chart of respondents' views on if integrating MR would enhance learning performance

Figure 3.30 presents a pie chart illustrating respondents' views on whether integrating mixed reality technologies would enhance students' learning performance in Physics education. 60% believe that mixed reality technologies would enhance learning, indicating strong support for their potential benefits. 0% think it would not enhance learning, reflecting no opposition. However, 40% are unsure, suggesting a significant portion of respondents are still evaluating the impact of these technologies on learning outcomes.

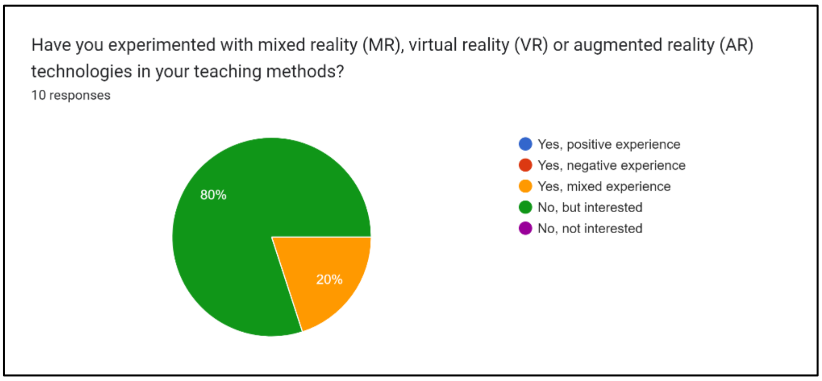


Figure 3.31: Pie chart of respondents' experiences with immersive technologies in teaching methods

Figure 3.31 displays a pie chart showing respondents' experiences with mixed reality (MR), virtual reality (VR), or augmented reality (AR) technologies in their teaching methods. Among the 10 respondents, 20% have had a mixed experience with these technologies, indicating some familiarity but varied outcomes. The majority, 80%, have not used these technologies but are interested in exploring them, reflecting a strong potential for future adoption. None of the respondents reported having a positive or negative experience, nor are any uninterested, suggesting a keen openness to integrating immersive technologies in teaching.

3.5.2.6 Section III (Non-Physics Individual) – Difficulty in Using Educational Applications

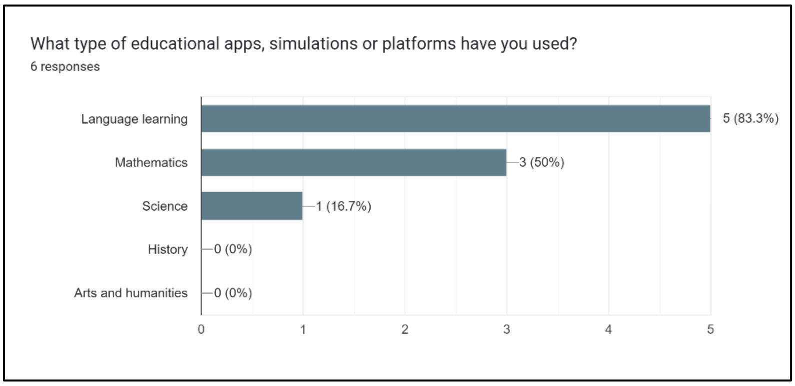


Figure 3.32: Bar chart of type of education apps used by the respondents

Figure 3.32 shows a bar chart detailing the types of educational apps, simulations, or platforms used by respondents. Out of 6 respondents, 83.3% have used apps for language learning, making it the most common category. 50% have utilized apps for mathematics, while 16.7% have engaged with science apps. No respondents reported using apps for history or arts and humanities, indicating a preference or need for educational resources in language and mathematics over other subjects.

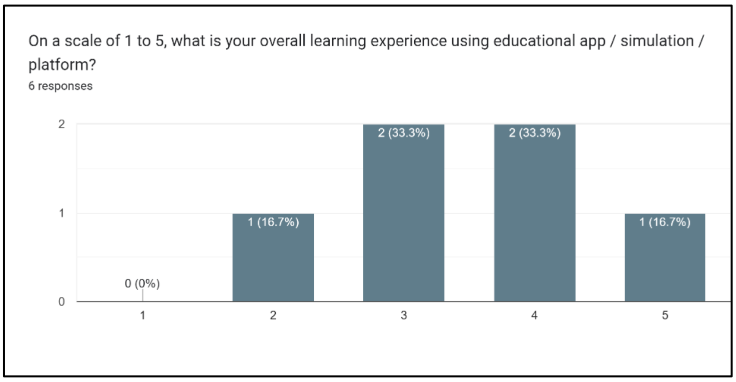


Figure 3.33: Column chart of respondents' overall learning experiences

Figure 3.33 presents a column chart evaluating overall learning experiences with educational apps, simulations, or platforms, based on responses from 6 individuals. The distribution is as follows: 16.7% rated their experience as 2, indicating a less favorable view. 33.3% rated it as 3 and another 33.3% as 4, suggesting a mixed but generally positive experience. Finally, 16.7% rated it as 5, reflecting a very positive experience. This chart highlights a range of satisfaction levels, with a tendency towards positive feedback.

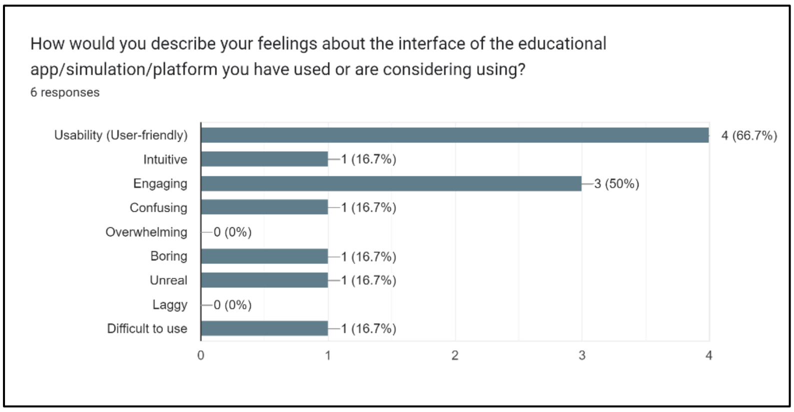


Figure 3.34: Bar chart of respondents' feelings about the educational app's interface

Figure 3.34 depicts a bar chart illustrating respondents' feelings about the interface of the educational app, simulation, or platform they have used or are considering. The results show that 66.7% of respondents found the interface user-friendly, indicating a high level of usability. 50% described the interface as engaging, while 16.7% found it intuitive, confusing, boring, unreal, or difficult to use. None of the respondents felt that the interface was overwhelming or laggy. This distribution highlights a generally positive reception, with specific areas for improvement in clarity and engagement.

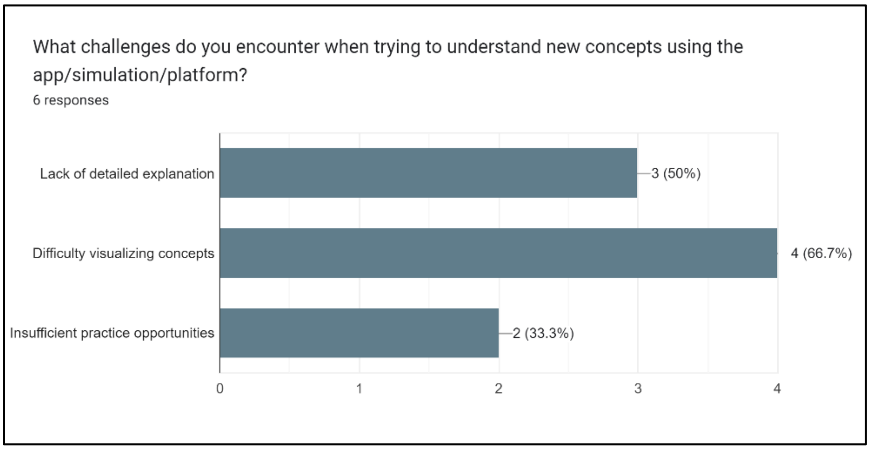


Figure 3.35: Bar chart of challenges faced by respondents when understanding new concepts

Figure 3.35 presents a bar chart showing challenges respondents face when trying to understand new concepts using an app, simulation, or platform. 66.7% of respondents reported difficulty visualizing concepts, while 50% noted a lack of detailed explanation as a challenge. 33% mentioned insufficient practice opportunities. These results indicate that while users find the visualization of concepts particularly challenging, there is also a need for more detailed explanations and practice opportunities to enhance their learning experience.

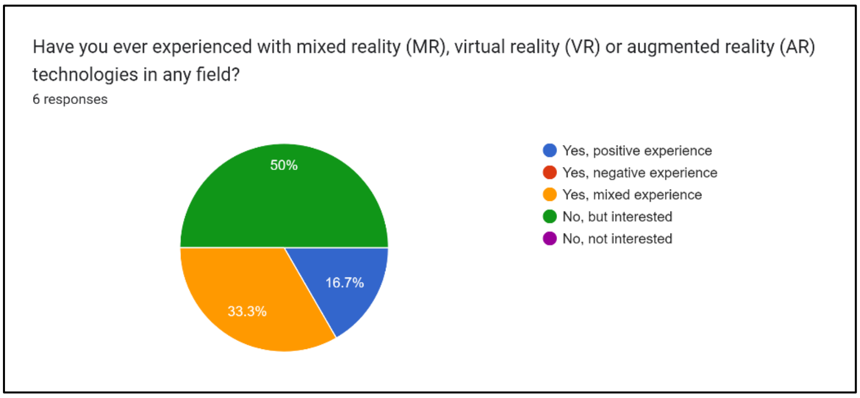


Figure 3.36: Pie chart of respondents' experiences with immersive technologies

Figure 3.36 is a pie chart illustrating respondents' experiences with mixed reality (MR), virtual reality (VR), or augmented reality (AR) technologies across various fields. 50% of respondents indicated no prior experience but expressed interest. 33.3% reported having mixed experiences with these technologies, while 16.7% had a positive experience. None of the respondents had a negative experience or were not interested. This suggests a general interest in MR, VR, and AR technologies, with a notable portion having mixed or positive experiences.

3.5.2.7 Section IV – Personal Experience towards Immersive Technologies Learners & Educators

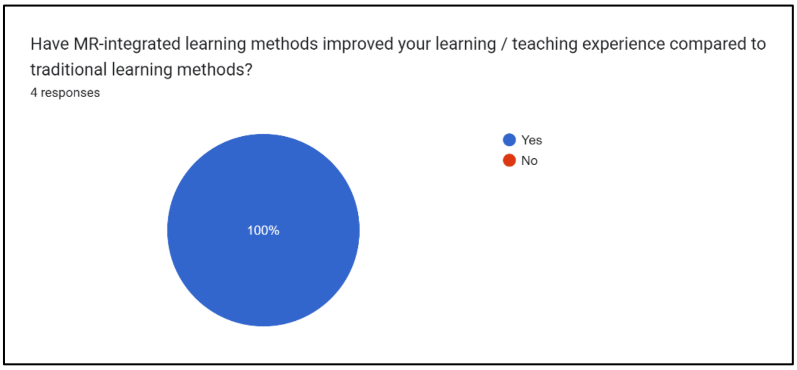


Figure 3.37: Pie chart showing impact of MR-integrated learning methods

Figure 3.37 is a pie chart depicting the impact of mixed reality (MR)-integrated learning methods compared to traditional learning methods. 100% of respondents indicated that MR-integrated learning methods have improved their learning or teaching experience, while 0% felt that MR methods did not make any improvement. This suggests unanimous positive feedback on the effectiveness of MR technologies in enhancing educational experiences.

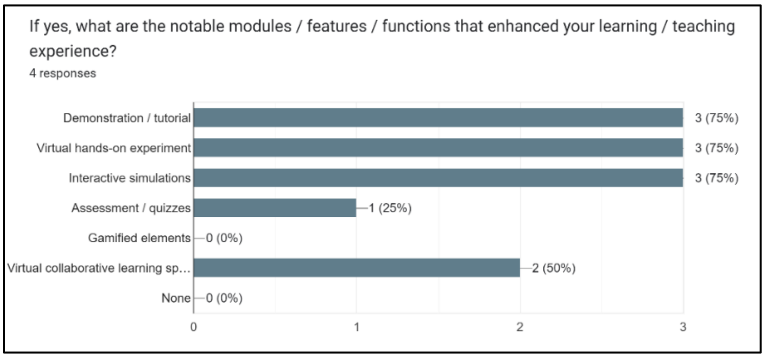


Figure 3.38: Bar chart of notable modules that enhanced respondents' experience

Figure 3.38 is a bar chart showing respondents' opinions on which modules, features, or functions notably enhanced their learning or teaching experience. 75% of respondents highlighted demonstrations/tutorials, virtual hands-on experiments, and interactive simulations as significant enhancers. 50% found virtual collaborative learning spaces beneficial, while 25% appreciated assessments/quizzes. 0% identified gamified elements and none as impactful. This indicates that practical and interactive components of the educational experience were most valued by the respondents.

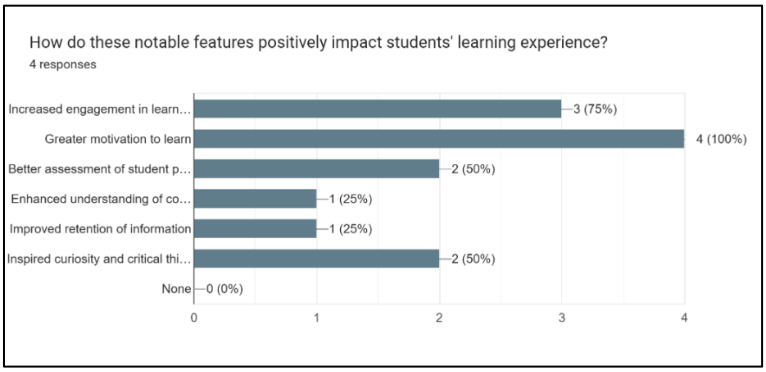


Figure 3.39: Bar chart showing how notable features impact students' learning experience

Figure 3.39 is a bar chart illustrating how notable features positively impact students' learning experiences. 100% of respondents indicated that these features greatly increased motivation to learn, while 75% noted an increase in engagement in learning activities. 50% observed better assessment of student progress and inspired curiosity and critical thinking, while 25% found an enhanced understanding of concepts and improved retention of information. No respondents felt that the features had no impact. This suggests that the highlighted features significantly contribute to various aspects of student engagement and motivation.

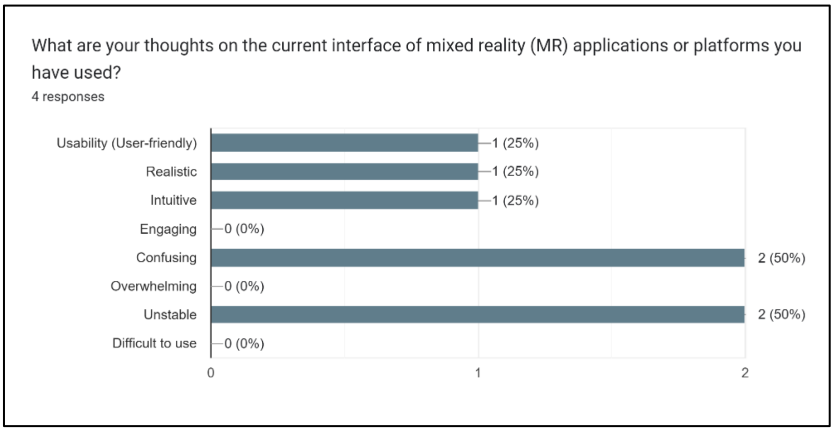


Figure 3.40: Bar chart of respondents' thoughts on the current MR app interface

Figure 3.40 is a bar chart depicting respondents' opinions on the current interface of mixed reality (MR) applications or platforms. 50% of respondents found the interfaces confusing and unstable, while 25% described them as user-friendly, realistic, and intuitive. No respondents reported that the interfaces were engaging, overwhelming, or difficult to use. This indicates that while some users find MR interfaces effective in certain areas, significant challenges with usability and stability remain.

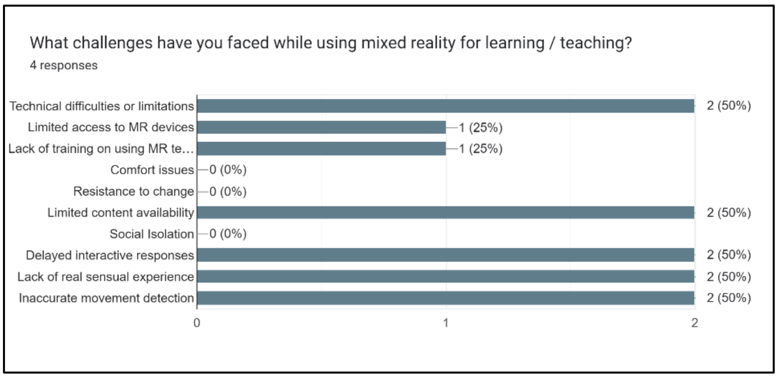


Figure 3.41: Bar chart of challenges faced by respondents while using MR

Figure 3.41 is a bar chart showing the challenges faced while using mixed reality (MR) for learning or teaching. 50% of respondents encountered technical difficulties or limitations, limited content availability, delayed interactive responses, lack of real sensual experience, and inaccurate movement detection. 25% faced issues with limited access to MR devices and lack of training on MR technology. None reported problems with comfort issues, resistance to change, or social isolation. This highlights a range of technical and logistical challenges impacting the effectiveness of MR applications in educational settings.

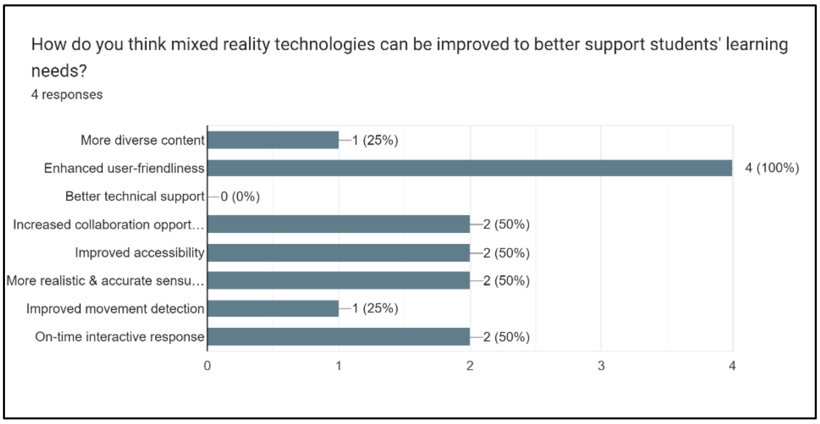


Figure 3.42: Bar chart of respondents' thoughts on how MR can be improved

Figure 3.42 is a bar chart illustrating suggestions for improving mixed reality (MR) technologies to better support students' learning needs. 100% of respondents emphasized the need for enhanced user-friendliness. 50% suggested improvements in increased collaboration opportunities, improved accessibility, more realistic and accurate sensual experience, and on-time interactive response. 25% recommended more diverse content and improved movement detection. This feedback highlights key areas for development to enhance the effectiveness of MR technologies in educational settings.

Non-Physics Individuals

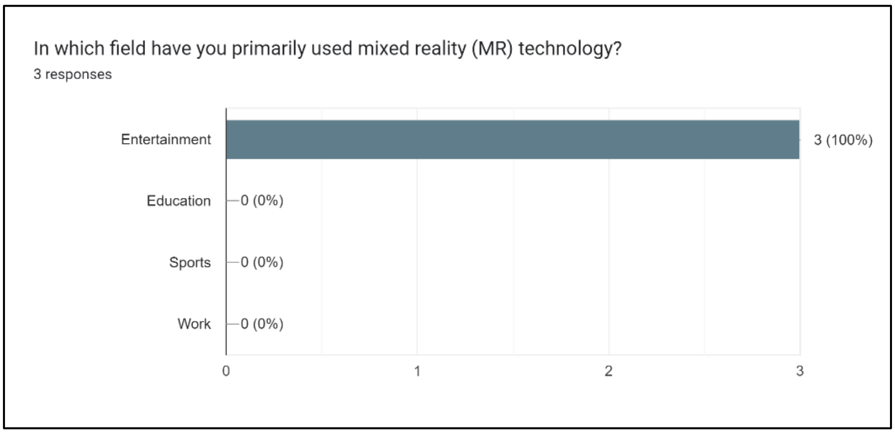


Figure 3.43: Bar chart of respondents' primary field of use for MR

Figure 3.43 is a bar chart showing the primary field of use for mixed reality (MR) technology among respondents. 100% of respondents reported using MR technology primarily for entertainment, while 0% used it for education, sports, or work. This indicates a predominant focus on entertainment applications rather than educational or professional uses.

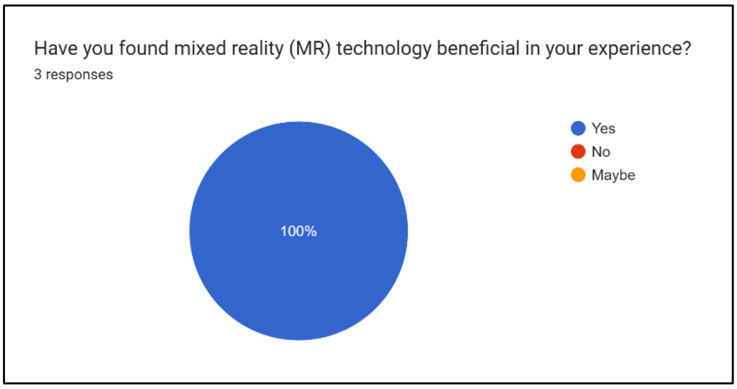


Figure 3.44: Pie chart showing the perceived benefit of MR among respondents

Figure 3.44 is a pie chart illustrating the perceived benefit of mixed reality (MR) technology among respondents. 100% of respondents found MR technology beneficial in their experience, with 0% reporting it as not beneficial or uncertain. This shows a unanimous positive evaluation of MR technology's usefulness.

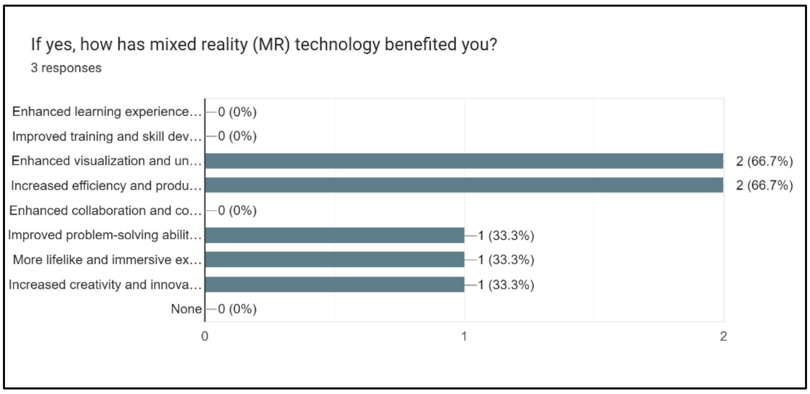


Figure 3.45:Bar chart of how MR benefited respondents

Figure 3.45 is a bar chart that shows how mixed reality (MR) technology has benefited respondents. 66.7% of respondents reported that MR technology enhanced visualization and understanding of complex concepts and increased efficiency and productivity in work tasks. 33.3% found it beneficial for improving problem-solving abilities, providing more lifelike and immersive experiences, and boosting creativity and innovation. No respondents indicated benefits in enhanced learning experiences, training, collaboration, or communication.

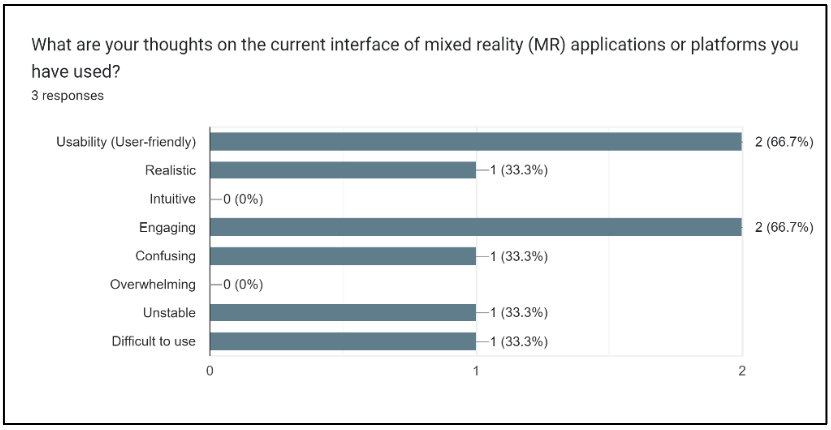


Figure 3.46: Bar chart of respondents' thoughts of current MR apps' interface

Figure 3.46 is a bar chart displaying opinions on the current interface of mixed reality (MR) applications or platforms. 66.7% of respondents found the interfaces to be user-friendly and engaging. 33.3% found them realistic, confusing, unstable, and difficult to use. None of the respondents considered the interfaces overwhelming or intuitive.

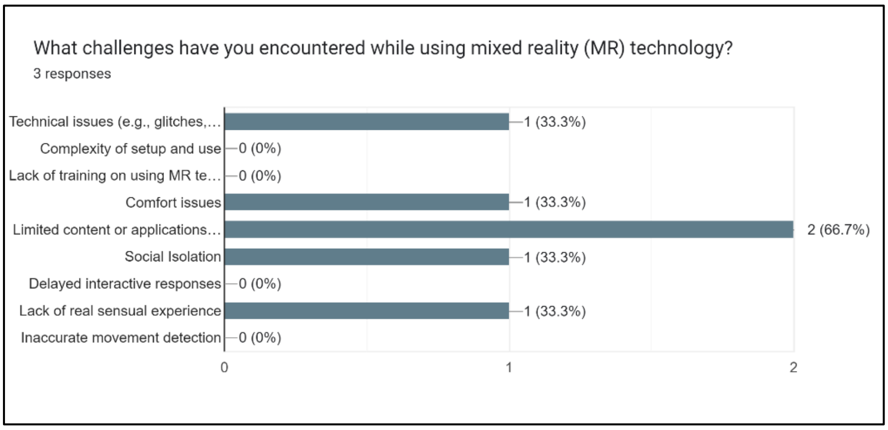


Figure 3.47: Bar chart of challenges faced by respondents while using MR

Figure 3.47 is a bar chart illustrating challenges encountered while using mixed reality (MR) technology. 66.7% of respondents reported issues with limited content or application availability. 33.3% faced technical issues, comfort problems, social isolation, lack of real sensual experience, and inaccurate movement detection. No respondents experienced challenges related to the complexity of setup, lack of training, delayed interactive responses, or movement detection.

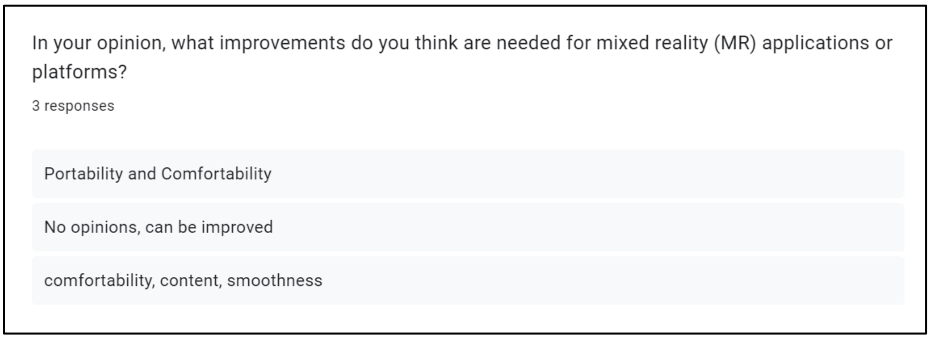


Figure 3.48: Responses of respondents' opinions on the improvements needed for MR apps

Figure 3.48 summarizes responses to an open-ended question about needed improvements for mixed reality (MR) applications or platforms. Respondents suggested enhancements in portability and comfort, with one noting a general need for improvement. Others emphasized comfort, content, and smoothness as areas requiring attention. Overall, the responses suggest that while MR technology shows promise, there are critical areas that need to be addressed to improve user satisfaction and effectiveness.

3.5.2.8 Section IV – Opinions towards Immersive Technologies

Physics Learner

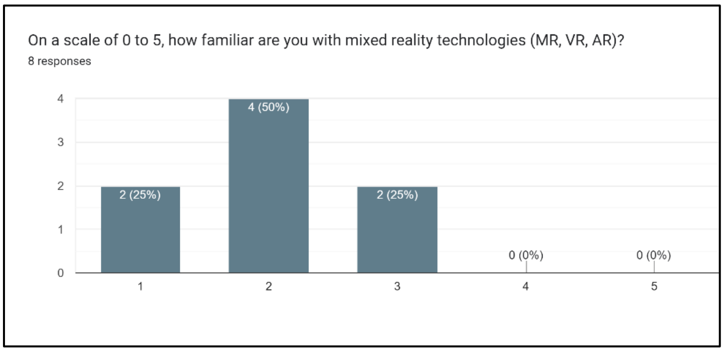


Figure 3.49: Column chart of respondents' familiarity towards MR

Figure 3.49 illustrates the respondents' familiarity with mixed reality technologies (MR, VR, AR) on a scale from 0 to 5. The chart indicates that 25% of respondents rated their familiarity as 1, 50% rated it as 2, and 25% rated it as 3. This distribution suggests varying levels of familiarity, with the majority having a moderate level of understanding.

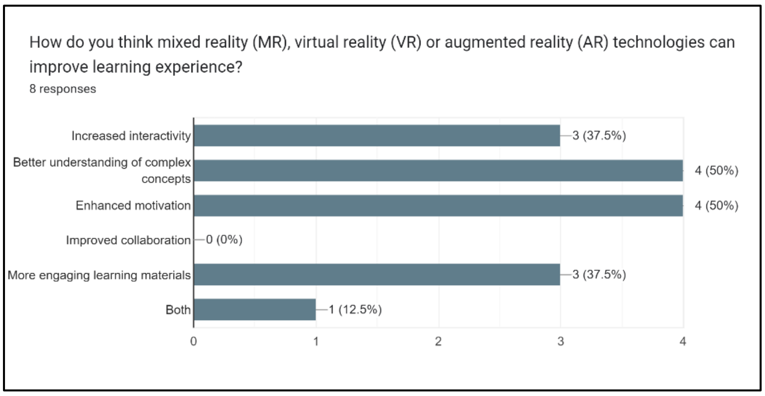


Figure 3.50: Bar chart of respondents' opinions on whether MR can improve learning experience

Bar chart above presents opinions on how MR, VR, and AR technologies can enhance learning experiences, based on 8 responses. The top perceived benefits are "Better understanding of complex concepts" and "Enhanced motivation," each selected by 50% of respondents. "Increased interactivity" and "More engaging learning materials" follow, each chosen by 37.5% of participants. One respondent (12.5%) selected "Both", likely indicating a combination of benefits. Notably, "Improved collaboration" received no responses. The chart suggests that respondents view these technologies as primarily beneficial for comprehension, motivation, and engagement in learning, while not associating them strongly with collaborative improvements.

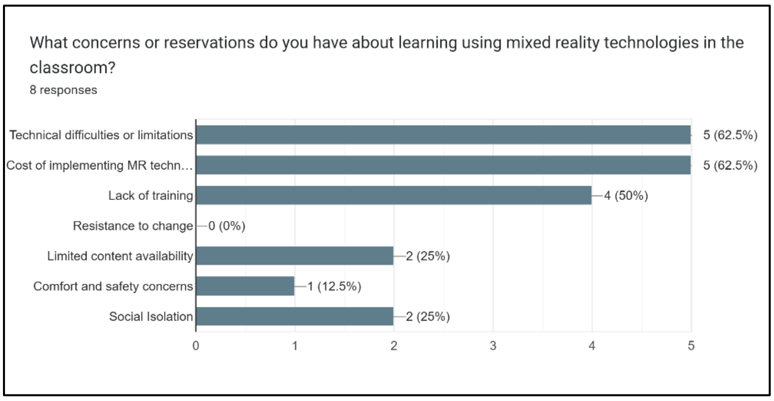


Figure 3.51: Bar chart of respondents' concerns about using MR in classroom

Bar chart above displays concerns about using mixed reality technologies in classrooms, based on 8 responses. The top concerns are "Technical difficulties or limitations" and "Cost of implementing MR tech," both at 62.5% (5 responses each). "Lack of training" follows at 50% (4 responses). "Limited content availability" and "Social isolation" each received 25% (2 responses), while "Comfort and safety concerns" was selected by 12.5% (1 response). Notably, "Resistance to change" received no responses. Respondents could select multiple options, indicating they have various concerns about implementing these technologies, with technical and cost issues being the most prominent.

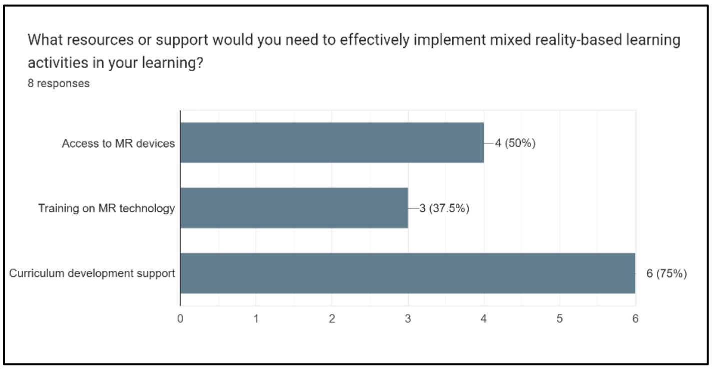


Figure 3.52: Bar chart of resources needed by respondents to effectively implement MR

Bar chart in Figure 3.52 shows the resources or support needed to implement mixed reality-based learning activities, based on 8 responses. The most commonly identified need is "Curriculum development support" at 75%, followed by "Access to MR devices" at 50%, and "Training on MR technology" at 37.5%. The data suggests that while hardware and training are important, curriculum development is seen as the most crucial support for effectively integrating mixed reality into learning activities.

Physics Educator

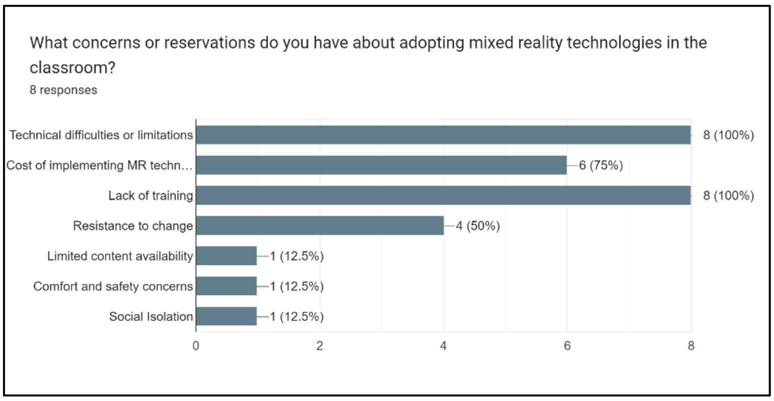


Figure 3.53: Bar chart of respondents' concerns about adopting MR in classroom

Figure 3.53 highlights that the predominant concerns about adopting mixed reality technologies in the classroom are technical difficulties and lack of training, both of which are cited by 100% of respondents. Additionally, 75% are concerned about the cost of implementation. Resistance to change is a concern for 50% of respondents, while issues such as limited content availability, comfort and safety concerns, and social isolation are less prominent, each noted by 12.5% of respondents.

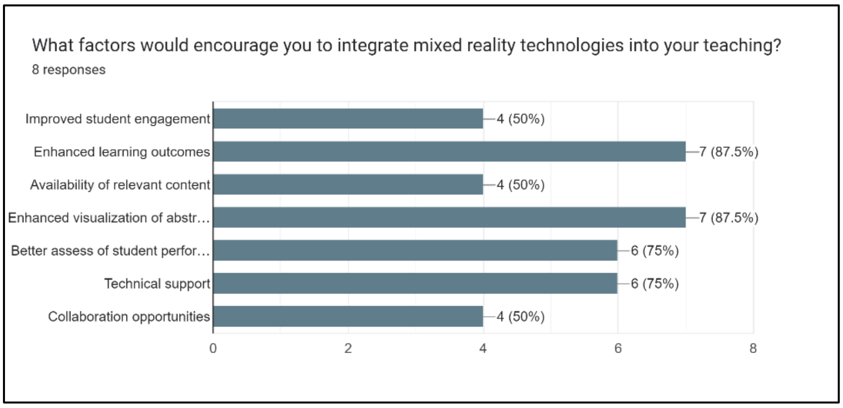


Figure 3.54: Bar chart of factors that would encourage respondents to integrate MR

Figure 3.54 shows that factors encouraging the integration of mixed reality technologies into teaching include enhanced learning outcomes and better visualization of abstract concepts, both highlighted by 87.5% of respondents. Improved student engagement, availability of relevant content, and collaboration opportunities are each supported by 50% of respondents. Additionally, 75% cite better assessment of student performance and technical support as motivating factors.

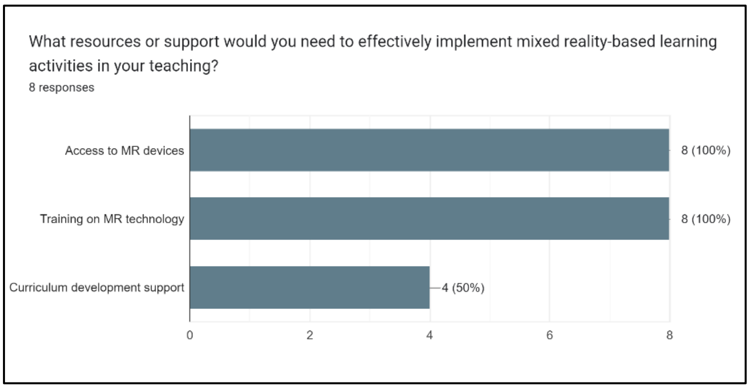


Figure 3.55: Bar chart of resources needed by respondent to implement MR

Figure 3.55 reveals that 100% of respondents identify access to MR devices and training on MR technology as essential resources for effectively implementing mixed reality-based learning activities. Additionally, 50% of respondents consider curriculum development support important for successful integration.

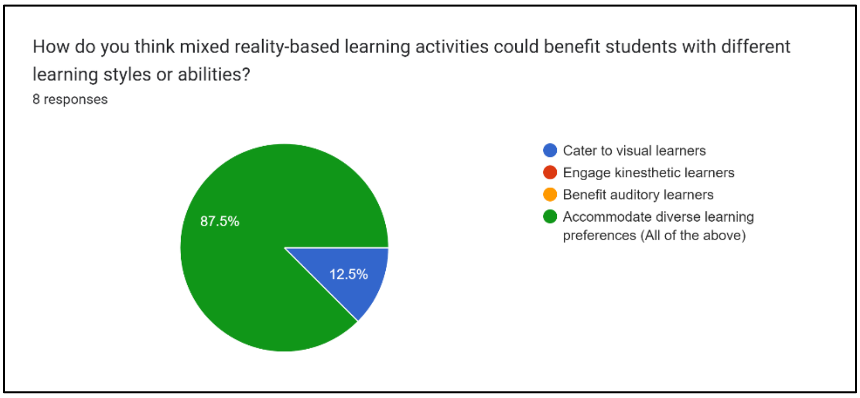


Figure 3.56: Pie chart of respondents' views on if MR could benefit students with different learning style

Figure 3.56 shows that 87.5% of respondents believe mixed reality-based learning activities can accommodate diverse learning preferences, covering visual, kinesthetic, and auditory learners. In contrast, only 12.5% think these activities specifically cater to visual learners, while none see benefits for kinesthetic or auditory learners individually.

Non-Physics Individuals

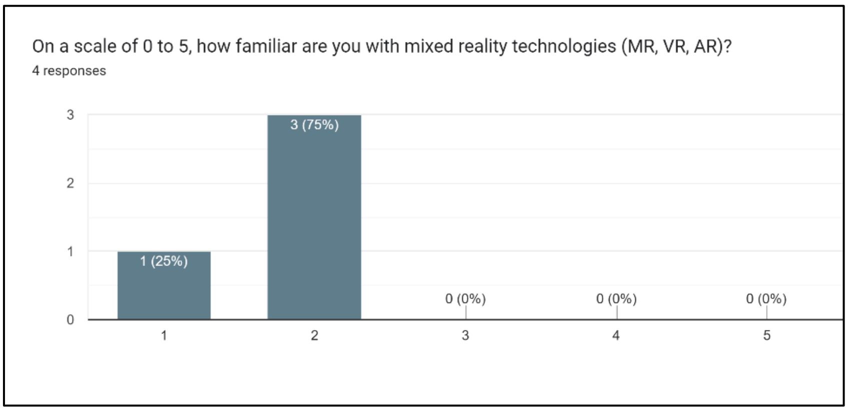


Figure 3.57: Column chart of respondents' familiarity with MR

Figure 3.57 indicates that among the 4 respondents, 25% are somewhat familiar with mixed reality technologies, rating their familiarity as 1, while a significant 75% rate their familiarity as 2, suggesting a basic or limited understanding of MR, VR, and AR technologies.

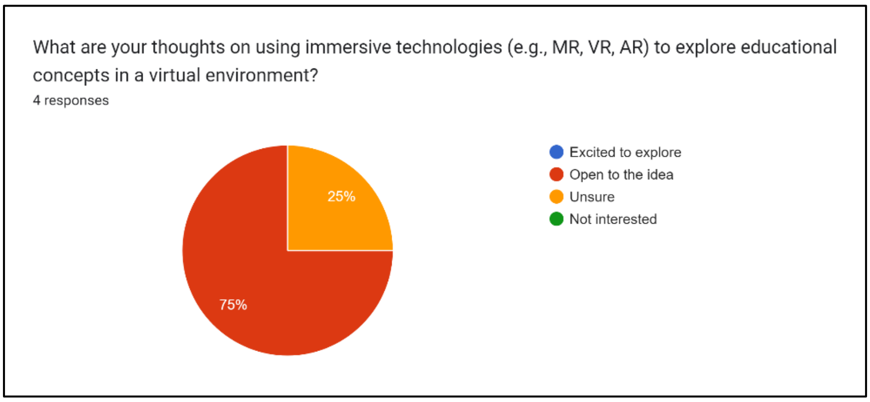


Figure 3.58: Pie chart of respondents' thoughts on using MR to explore educational concepts

Figure 3.58 shows that among the 4 respondents, 75% are open to the idea of using immersive technologies like MR, VR, and AR for exploring educational concepts, while 25% are unsure about it. None of the respondents are excited to explore or not interested in using these technologies.

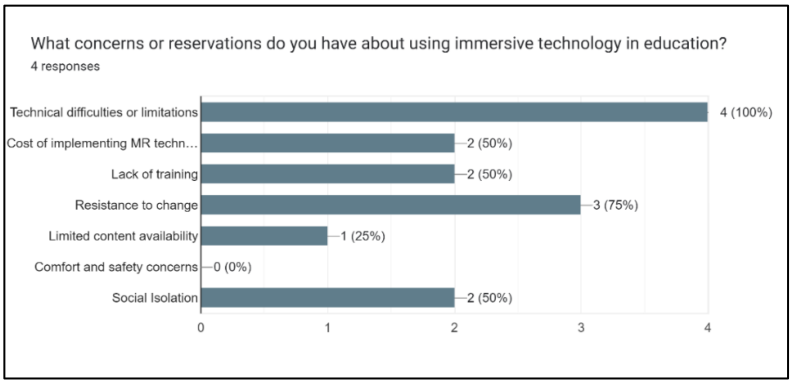


Figure 3.59: Bar chart about respondents' concerns about using immersive technology

Figure 3.59 highlights several concerns about using immersive technology in education among 4 respondents. The most prominent issue, with 100% of respondents, is technical difficulties or limitations. Resistance to change is also a significant concern for 75% of respondents. Other concerns include the cost of implementing MR technology, lack of training, and social isolation, each noted by 50% of respondents. Limited content availability was a concern for 25%, while comfort and safety issues were not mentioned.

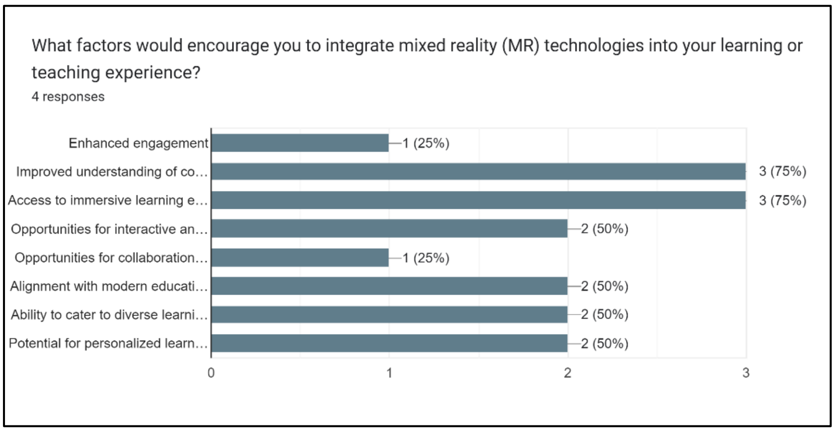


Figure 3.60: Bar chart of factors that would encourage respondents to integrate MR

Figure 3.60 illustrates factors that could encourage the integration of mixed reality (MR) technologies into learning or teaching among 4 respondents. The most influential factors are improving understanding of complex concepts and access to immersive learning experiences, each supported by 75% of respondents. Opportunities for interactive and hands-on learning is valued by 50%, while enhanced engagement, collaboration and teamwork, alignment with modern educational trends, catering to diverse learning styles, and personalized learning experiences each received varied support, ranging from 25% to 50%.

3.5.2.9 Section V – Functions & Features

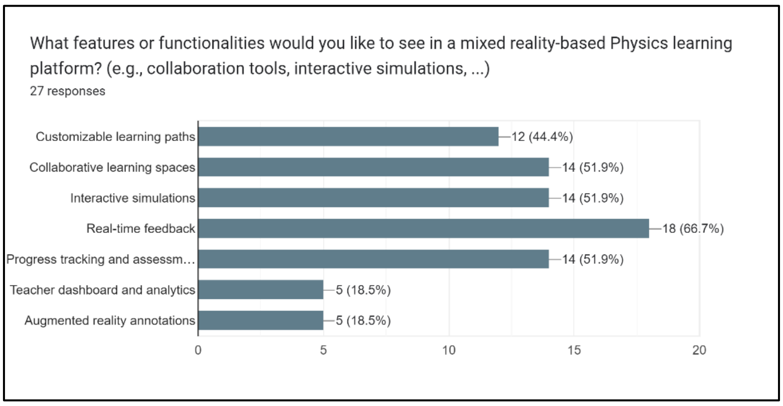


Figure 3.61: Bar chart of respondents' opinions on features to be seen in a MR Physics app

Figure 3.61 shows the desired features for a mixed reality-based Physics learning platform from 27 respondents. The most favored feature is real-time feedback, preferred by 66.7% of respondents. Collaborative learning spaces, interactive simulations, and progress tracking and assessment each received substantial support of 51.9%. Customizable learning paths were selected by 44.4%, while teacher dashboards, analytics, and augmented reality annotations were less favored, with support ranging from 18.5% to 18.6%.

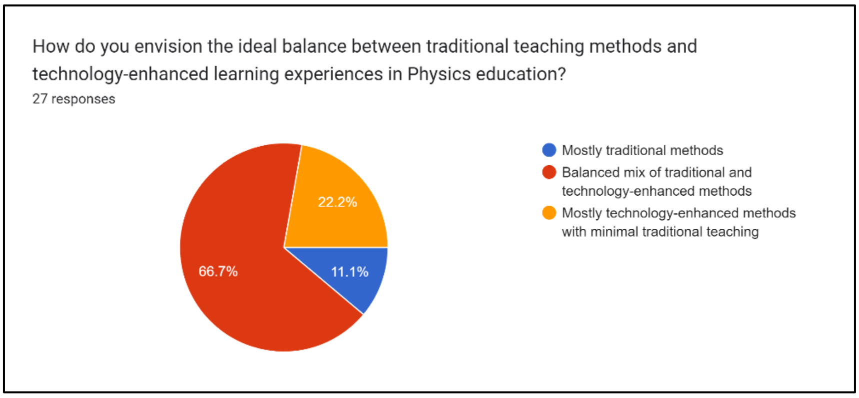


Figure 3.62: Pie chart of respondents' envision of the ideal balance between traditional and technology-enhanced learning experiences

Figure 3.62 illustrates preferences for balancing traditional and technology-enhanced teaching methods in Physics education among 4 respondents. The majority (66.7%) favor a balanced mix of traditional and technology-enhanced methods. A smaller segment (22.2%) prefers mostly technology-enhanced methods with minimal traditional teaching, while only 11.1% favor primarily traditional methods. This indicates a strong inclination towards integrating both approaches for effective Physics education.

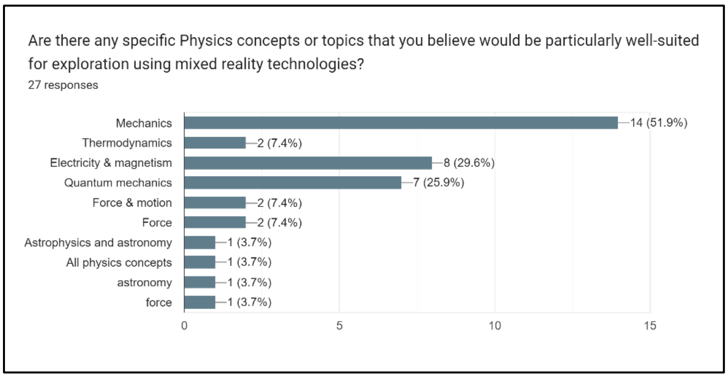


Figure 3.63: Bar chart of specific Physics concepts that respondents believe would be suitable to explore

Figure 3.63 shows the perceived suitability of various Physics concepts for exploration using mixed reality technologies among 27 respondents. Mechanics is considered the most suitable, with 51.9% of respondents highlighting its effectiveness. Electricity and magnetism follow at 29.6%, while quantum mechanics is seen as suitable by 25.9%. Thermodynamics is less favored at 7.4%. Other concepts mentioned include force and motion (7.4%), force alone (11.1%), and astrophysics and astronomy (7.4%). A small fraction (3.7%) believes that all Physics concepts could benefit from mixed reality. This distribution reflects a preference for applying mixed reality to complex and abstract concepts, with varying degrees of interest in other topics.

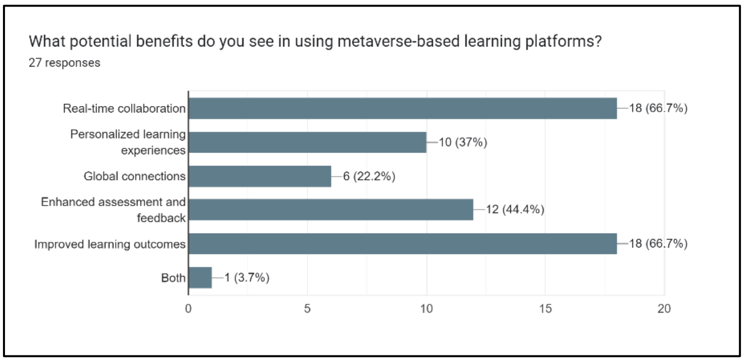


Figure 3.64: Bar chart of potential benefits respondents see in using MR learning platforms

Figure 3.3 displays the potential benefits of using metaverse-based learning platforms as perceived by 27 respondents. The most cited benefits are real-time collaboration and improved learning outcomes, both at 66.7%. Enhanced assessment and feedback is also valued by 44.4% of respondents, while personalized learning experiences and global connections are seen as beneficial by 37% and 22.2%, respectively. This chart highlights a strong emphasis on collaboration and outcome improvement through metaverse technologies.

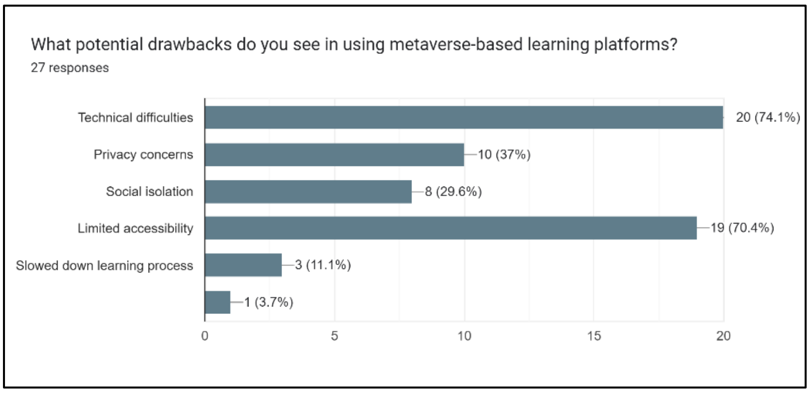


Figure 3.65: Bar chart of potential drawbacks respondents see in using MR learning platforms

Figure 3.65 illustrates the perceived drawbacks of using metaverse-based learning platforms among 27 respondents. Technical difficulties are the most commonly noted concern, with 74.1% citing this issue. Limited accessibility is also a significant concern, affecting 70.4% of respondents. Privacy concerns and social isolation are noted by 37% and 29.6%, respectively. A smaller percentage, 11.1%, are worried about a slowed-down learning process. This chart emphasizes technical and accessibility challenges as the primary drawbacks.

3.6 Requirement Specification

The requirement specification for this project outlines the functional and non-functional needs of the system to ensure it meets its intended goals of enhancing Physics education through immersive technologies. This section details both the essential features and operations that the application must support, as well as the quality standards it must adhere to for optimal performance, usability, and user satisfaction. These requirements are informed by the project objectives, focusing on creating a highly interactive, user-friendly, and educational platform that integrates MR elements, gamification, and collaborative learning tools.

The functional requirements describe the specific tasks the system must perform, such as user interactions, scene transitions, and real-time Physics experiments. Meanwhile, the non-functional requirements ensure that the system operates smoothly, reliably, and efficiently, covering aspects like performance, security, compatibility, and scalability. These combined requirements provide a roadmap for the successful development and deployment.

3.6.1 Functional Requirements

The functional requirements define the specific behaviours and functions that the system must exhibit. For this application, these include:

1. **Main Menu Navigation:**
   - The system must provide an interactive main menu that allows users to select subtopics represented by animated objects.
   - Users must be able to navigate between different modules (Tutorial, Hands-on Experiment, Interactive Assessment, Gamification Elements, Collaborative Learning Space) from the main menu and topic menu.
   - Buttons for settings, audio, and exit options must be functional and provide feedback when clicked.
2. **Conceptual Demonstration / Tutorials Module**:
   - The system must provide tutorial modules for each Physics topic (e.g., Free Fall, Force) with step-by-step instructional content.
   - Users must be able to interact with the tutorial via UI buttons and navigation controls to progress through lessons.
3. **Hands-on Experiment Module**:
   - The system must allow users to interact with MR experiments related to Physics topics.
   - Users must be able to manipulate objects (e.g., dragging and dropping masses or adjusting forces) to observe the effects in real-time (e.g., free fall motion, force, and acceleration).
   - The system must display key data (e.g., time, speed, force, height, acceleration) in the experiment interface.
4. **Interactive Assessment Module**:
   - The system must provide multiple-choice questions for users to test their knowledge.
   - The assessment module must include a Toggle Group for answer selection and display real-time feedback after each question.
   - The system must calculate and display the total correct answers, as well as show XP points earned by the user at the end of the lesson.
5. **Gamification Elements Module**:

- The system must include a gamification feature with badges, leaderboards, and quizzes to motivate user engagement.
- Users should be able to track their progress, earn badges, and compete with friends in quizzes integrated through platforms like Kahoot.

6. **Collaborative Learning Space Module**:
    - The system must provide a collaborative learning environment where users can interact with peers.
7. **Scene Loading and Transitions**:
    - The system must manage seamless scene transitions when users navigate between different modules.

3.6.2 Non-Functional Requirements

The non-functional requirements outline the system's quality attributes, ensuring smooth operation and optimal user experience.

1. **Performance**:
    - The application must maintain a smooth frame rate during MR interactions, with minimal lag or delay.
    - The system must optimize loading times for each scene and ensure that transitions between modules do not exceed 5 seconds.
    - The application must function without crashing on devices meeting minimum hardware specifications.
2. **Usability**:
    - The UI must be intuitive and easy to navigate for users of all ages, particularly for students and educators.
    - The application should provide tooltips or hints when users hover over interactive elements, improving accessibility.
    - The assessment module must offer clear feedback on correct and incorrect answers to guide user learning.
3. **Compatibility**:
    - The system must be compatible with standard desktop computers, laptops, and VR headsets.
    - The VR/AR modules must be functional across a range of supported devices, with a focus on high-performance hardware for the best experience.

- Users must be able to operate the application with standard keyboard/mouse input as well as VR controllers.

4. **Scalability**:
   - The application must support the addition of more Physics topics and content in future versions without requiring major restructuring of the core system.
   - The collaborative learning space must allow for future expansion to accommodate larger groups of users.
5. **Security**:
   - The system must ensure secure handling of user credentials and personal data using encryptions for all sensitive information.
   - The application must comply with general data protection regulations to ensure user privacy and data safety.
6. **Reliability**:
   - The system must be stable and reliable, with less than 2% downtime over a 12-month period.
   - It must provide error-handling mechanisms to alert users in case of failures and allow them to report bugs or issues easily.
7. **Battery and Power Consumption**
   - The application must be optimized to minimize power consumption, especially during intensive VR/AR interactions, to extend device battery life.
8. **Maintainability**
   - The system architecture must be modular, allowing for easy updates and maintenance of individual components.
   - The codebase must be well-documented to facilitate future development and debugging.

3.7 System Design

In system design, system flow diagrams and prototypes will be covered. Flow diagrams provide an overview of data and process flow, while prototypes offer tangible representations of system interfaces and functionality. These tools facilitate communication, optimize workflows, and ensure alignment with user requirements, driving successful system development

3.7.1 System Flow Diagram

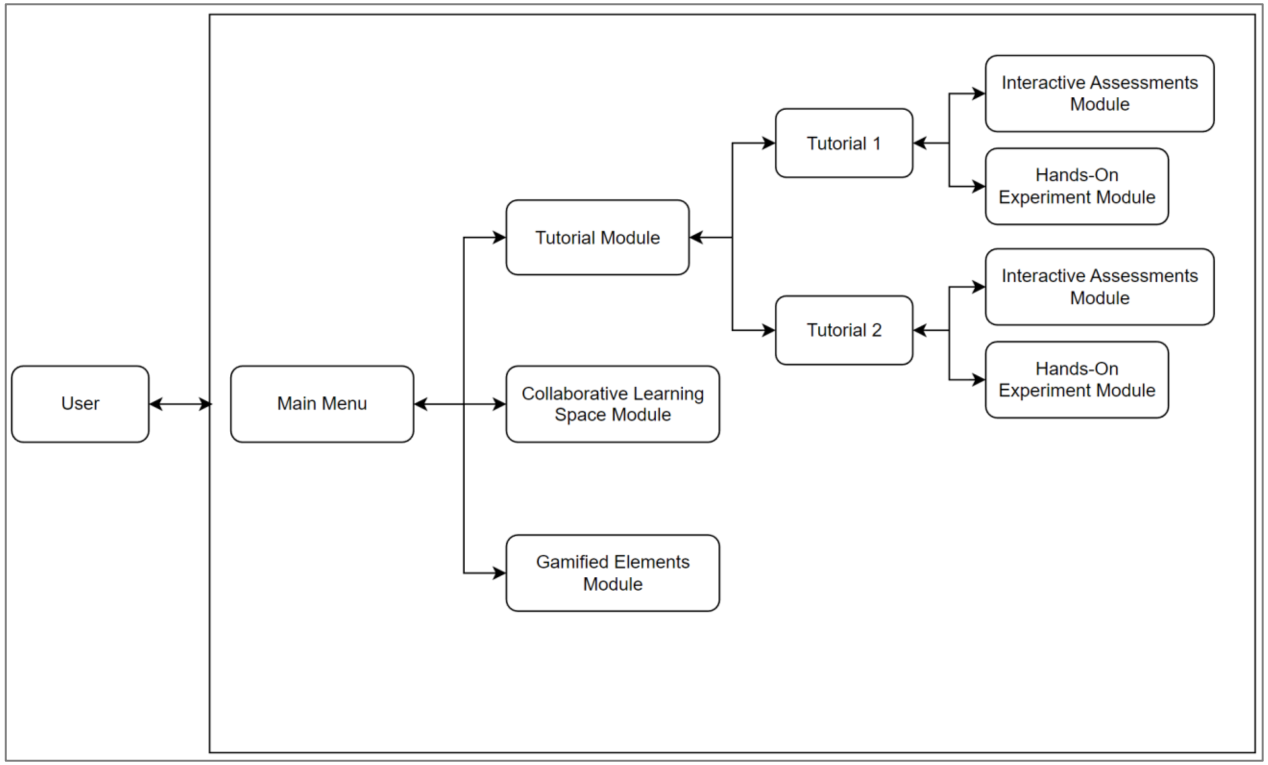


Figure 3.66: System Flow Diagram of Proposed System

Source: Created by the author

3.7.2 Storyboard

3.7.2.1 Start Menu

Storyboard No.: 1

Components: T (Text), G (Graphic), Ad (Audio), An (Animation), B (Button), O (Others)

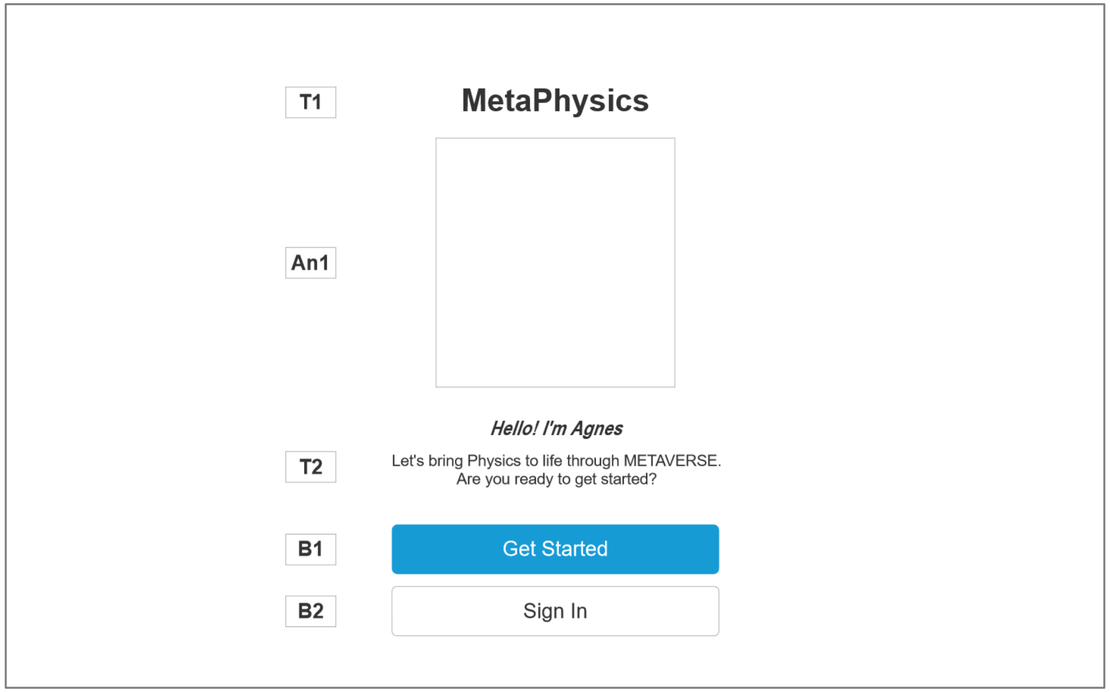
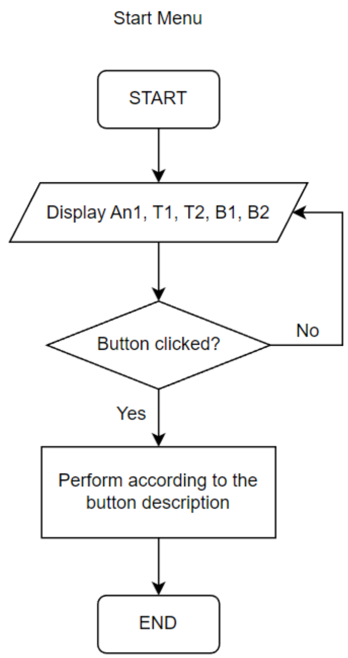


Figure 3.67: Start Menu Storyboard

Source: Created by the author

Table 3.4: Description and flow diagram of start menu

Description	**Flow Diagram**
An1: An1 is the animation of virtual agent on Start Menu. **T1:** T1 is the name of the application. **T2:** T2 is the text to welcome and prompt user. **B1:** B1 is the button navigation to create account page. **B2:** B2 is the button navigate to sign in page.	

Source: Created by the author

3.7.2.2 Main Menu

Storyboard No.: 2

Components: T (Text), G (Graphic), Ad (Audio), An (Animation), B (Button), O (Others)

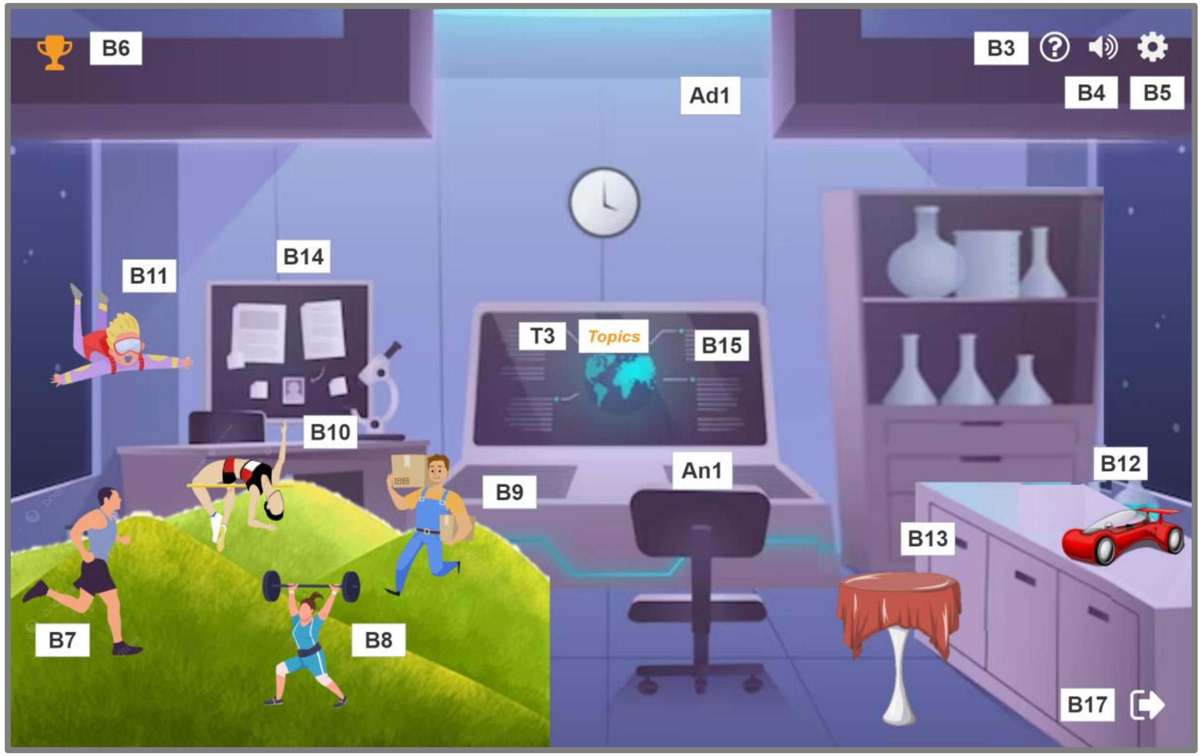
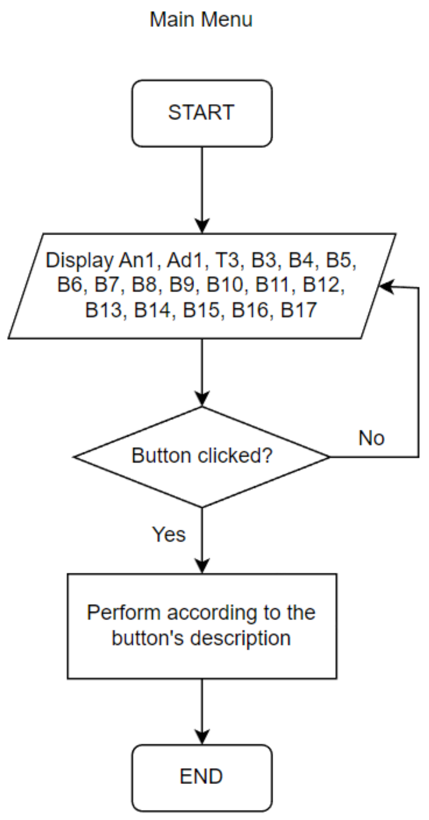


Figure 3.68: Main Menu Storyboard

Source: Created by the author

Table 3.5: Description and flow diagram of main menu

Description	Flow Diagram
An1: An1 is the animation of virtual agent on Main Menu. **Ad1:** Au1 is the background music of Main Menu. **T3:** T3 is the "Topics" title. **B3:** B3 is the button for hint / help menu. **B4:** B4 is the button to switch on or off the background music. **B5:** B5 is the button direct to user setting. **B6:** B6 is the button navigate to gamified elements module. **B7:** B7 is the button navigate to linear motion course. **B8:** B8 is the button navigate to weight course. **B9:** B9 is the button navigate to force course. **B10:** B10 is the button navigate to impulse and impulsive force course. **B11:** B11 is the button navigate to free fall motion course. **B12:** B12 is the button navigate to momentum course. **B13:** B13 is the button navigate to inertia course. **B14:** B14 is the button navigate to collaborative learning space module.	

B15: B15 is the button navigate to alternative topic selection page. **B17:** B17 is the button used to sign out of the account.	

Source: Created by the author

3.7.2.3 Topic Selection Page

Storyboard No.: 3

Components: T (Text), G (Graphic), Ad (Audio), An (Animation), B (Button), O (Others)

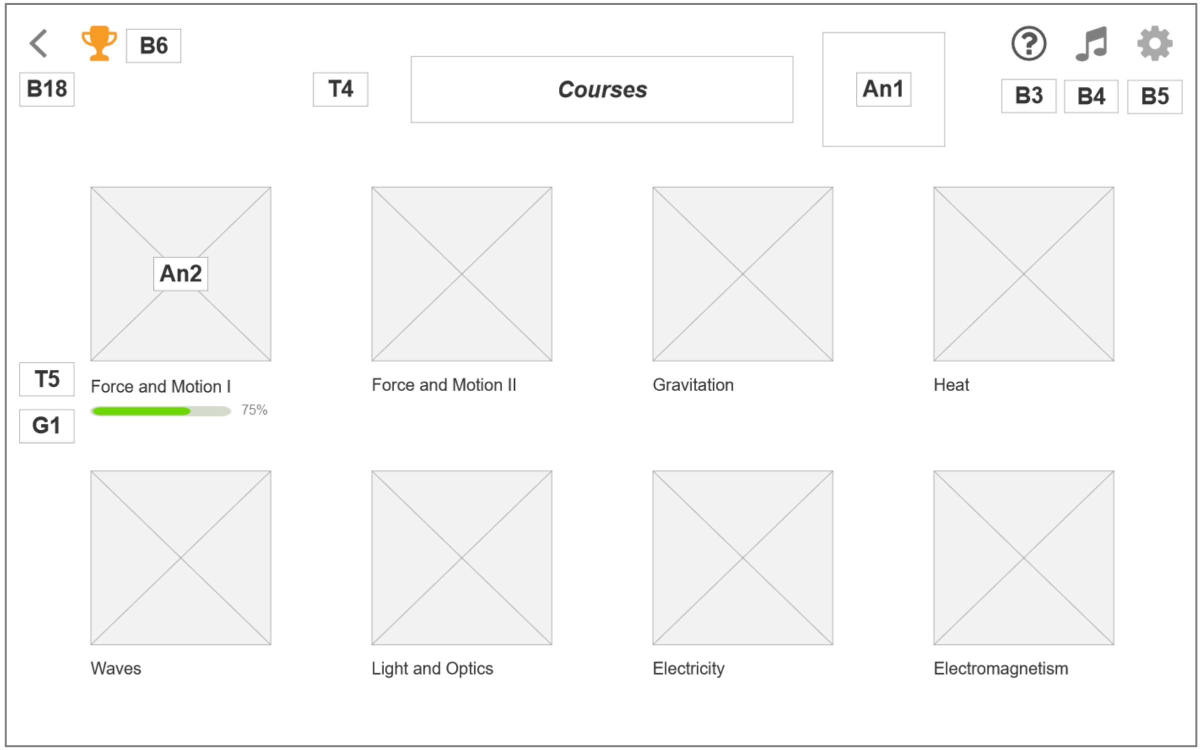
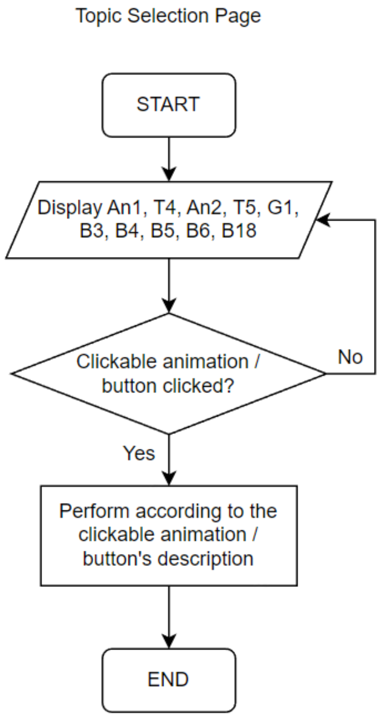


Figure 3.69: Topic Selection Page Storyboard

Source: Created by the author

Table 3.6: Description and flow diagram of topic selection page

Description	**Flow Diagram**
An1: An1 is the animation of virtual agent on topic selection page. **T4:** T4 is the “Courses” title. **An2:** An2 is a clickable animation of each course. **T5:** T5 is the title of each course. **G1:** G1 is the process bar graphic element of ongoing course. **B3:** B3 is the button for hint / help menu. **B4:** B4 is the button to switch on or off the background music. **B5:** B5 is the button direct to user setting. **B6:** B6 is the button navigate to gamified elements module. **B18:** B18 is the button navigate to previous page (main menu).	

Source: Created by the author

3.7.2.4 Course Page with Stages

Storyboard No.: 4

Components: T (Text), G (Graphic), Ad (Audio), An (Animation), B (Button), O (Others)

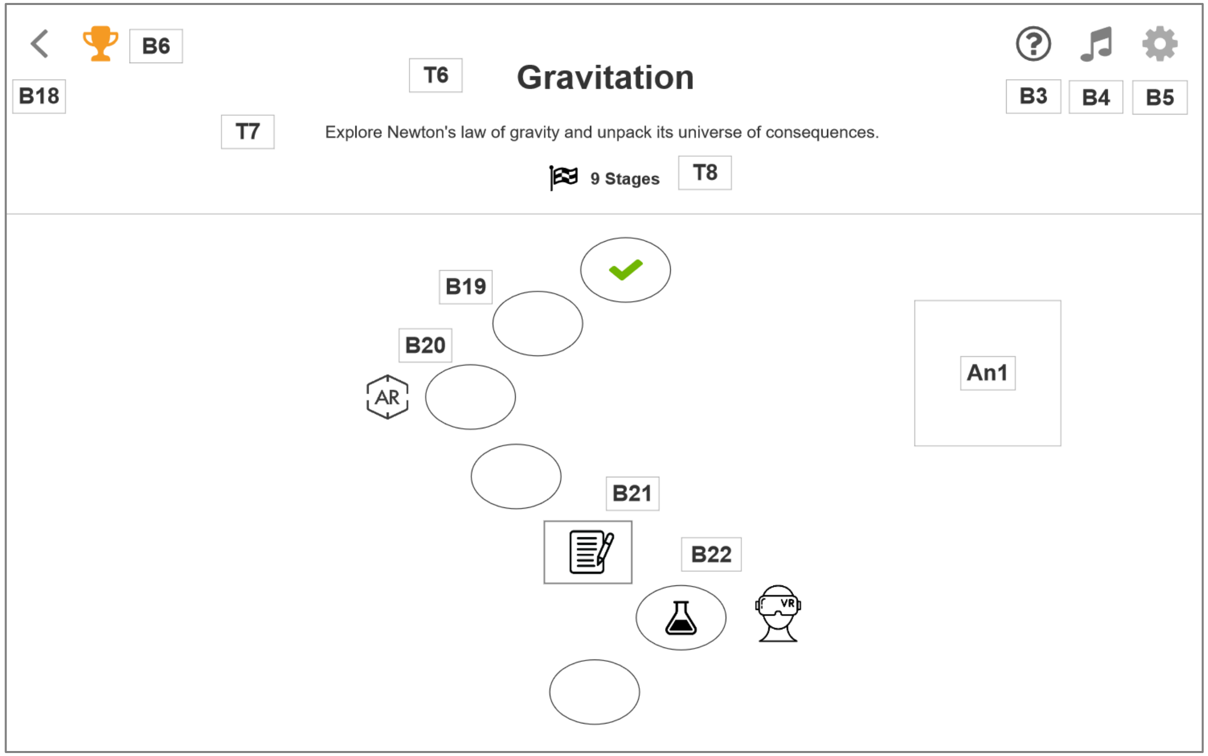
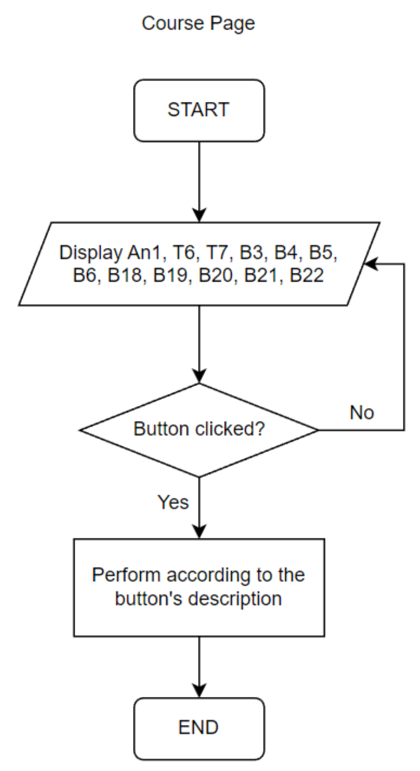


Figure 3.70: Course Page with Stages Storyboard

Source: Created by the author

Table 3.7: Description and flow diagram of course page

<table>
<tr><th>Description</th><th>Flow Diagram</th></tr>
<tr><td>
An1: An1 is the animation of virtual agent on course page.
T6: T6 is the title of the course.
T7: T7 is the description of the course.
T8: T8 is the text indicating the number of stages / lessons of the course.
An2: An2 is a clickable animation of each course.
B3: B3 is the button for hint / help menu.
B4: B4 is the button to switch on or off the background music.
B5: B5 is the button direct to user setting.
B6: B6 is the button navigate to gamified elements module.
B18: B18 is the button navigate to previous page.
B19: B19 is the button navigate to demonstration / tutorials module using text, graphic, audios, and / or video contents.
B20: B20 is the button navigate to demonstration / tutorials module integrating AR.
B21: B21 is the button navigate to interactive assessments module.
B22: B22 is the button navigate to hands-on experiment module incorporating VR.
</td><td>


</td></tr>
</table>

Source: Created by the author

3.7.2.5 Demonstration / Tutorials Module

Storyboard No.: 5

Components: T (Text), G (Graphic), Ad (Audio), An (Animation), B (Button), O (Others)

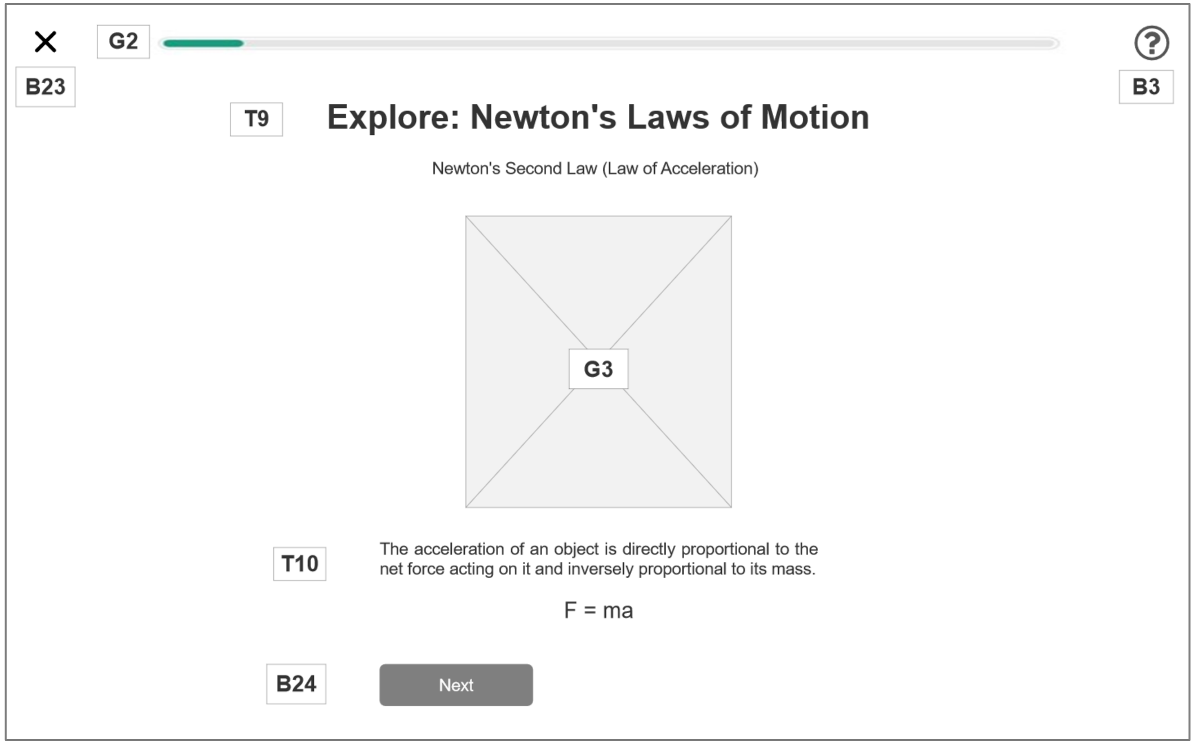


Figure 3.71: Demonstration / Tutorials Storyboard

Source: Created by the author

Table 3.8: Description and flow diagram of tutorials module

<table>
<tr><th>Description</th><th>Flow Diagram</th></tr>
<tr><td>

G2: G2 is the progress bar of this module.

G3: G3 is the graphic for content demonstration.

T9: T9 is the title of this module.

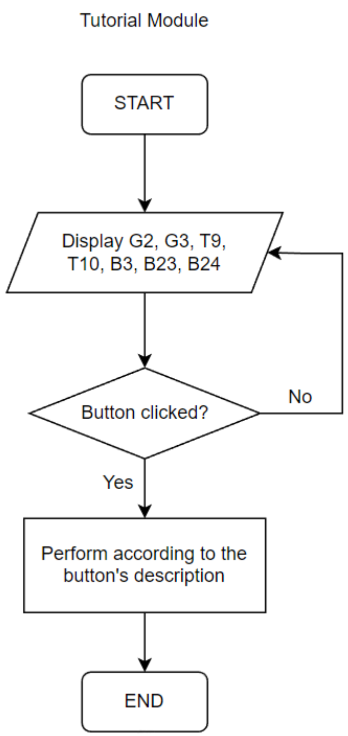
T10: T10 is the explanation of this module.

B3: B3 is the button for hint / help menu.

B23: B23 is the button to withdraw from this tutorial module.

B24: B24 is the button to expand the next theory explanation.

</td><td>



</td></tr>
</table>

Source: Created by the author

3.7.2.6 Demonstration / Tutorials Module with AR

Storyboard No.: 6

Components: T (Text), G (Graphic), Ad (Audio), An (Animation), B (Button), O (Others)

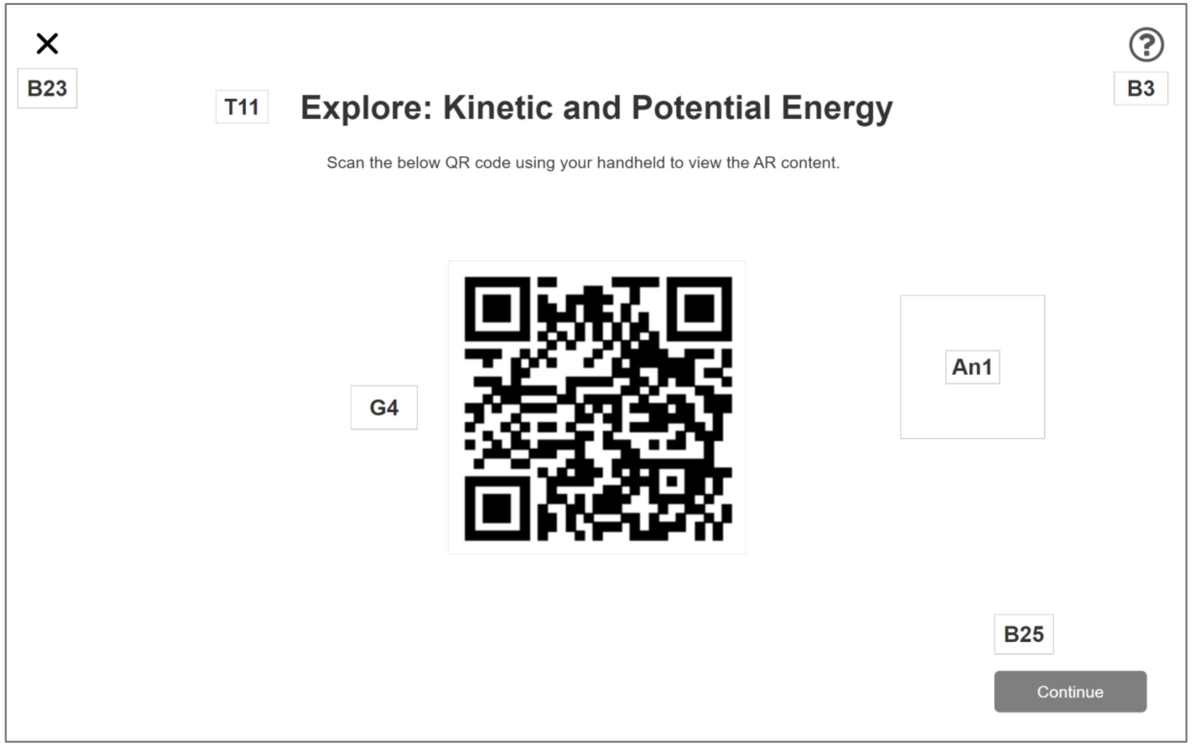
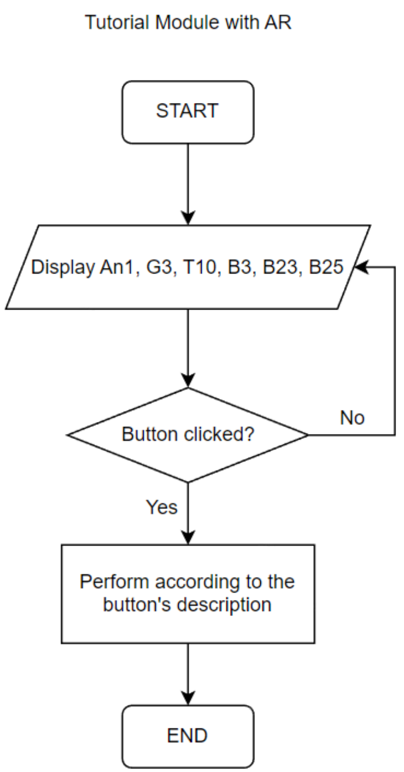


Figure 3.72: Demonstration / Tutorials with AR Storyboard

Source: Created by the author

Table 3.9: Description and flow diagram of tutorials module with AR

Description	**Flow Diagram**
An1: An1 is the animation of virtual agent on tutorial module. **G3:** G3 is the graphic for scanning to view AR content demonstration on another devices. **T10:** T10 is the title of this module. **B3:** B3 is the button for hint / help menu. **B23:** B23 is the button to withdraw from this tutorial module. **B25:** B25 is the button to continue to next action.	

Source: Created by the author

3.7.2.7 Demonstration / Tutorials Module with AR (on handheld devices)

Storyboard No.: 7

Components: T (Text), G (Graphic), Ad (Audio), An (Animation), B (Button), O (Others)

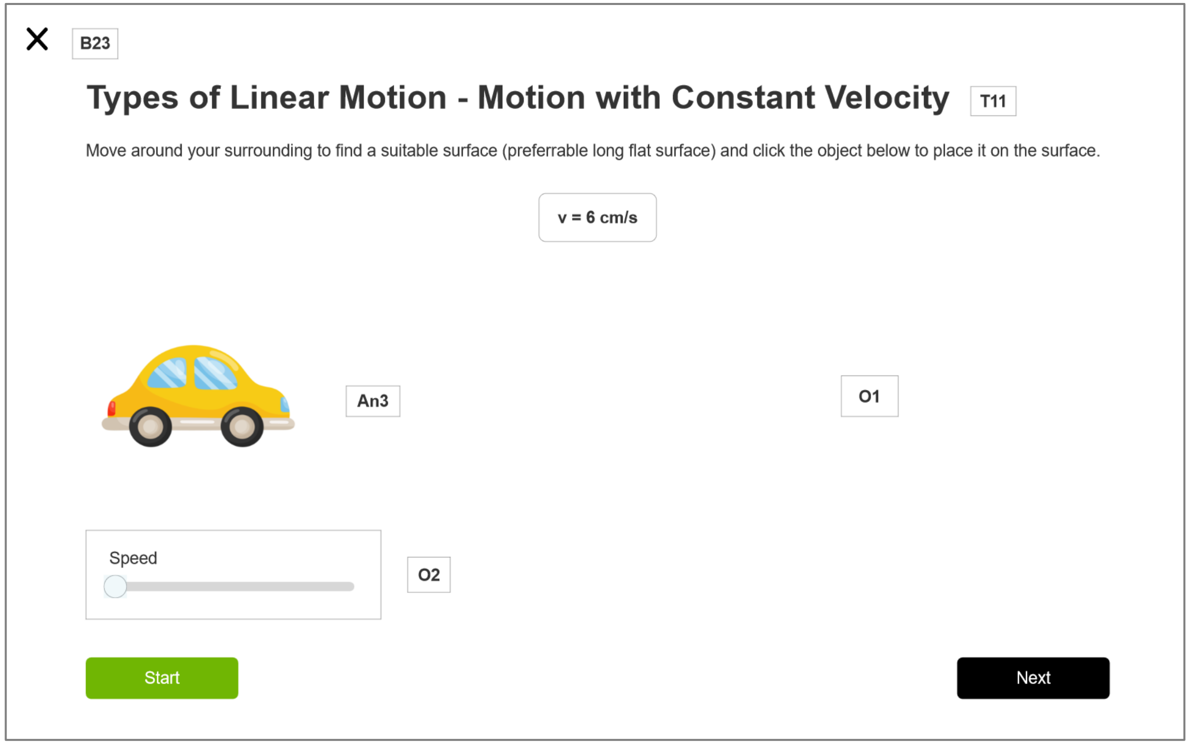
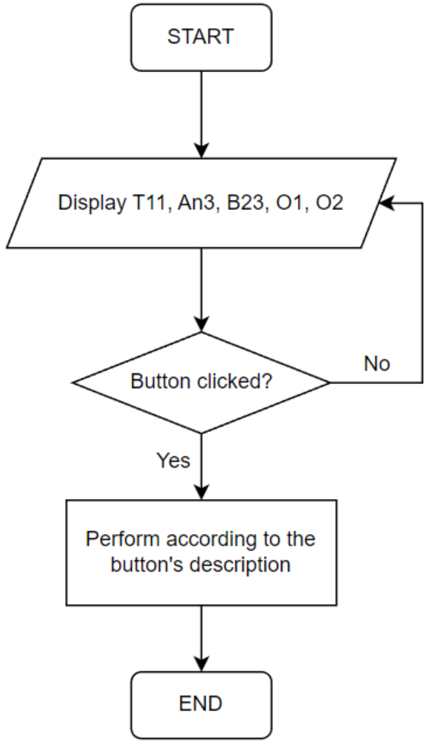


Figure 3.73: Demonstration / Tutorials with AR (on handheld devices) Storyboard

Source: Created by the author

Table 3.10: Description and flow diagram of tutorials module with AR (on handheld devices)

Description	**Flow Diagram**
T11: T11 is the title & explanation of this module. **An3:** An3 is the animation of AR content for demonstration. **B23:** B23 is the button to withdraw from this interface. **O1:** O1 is the real-life background captured from users' surroundings. **O2:** O2 is the adjustable parameters region to explore various scenarios and observe the result of the AR content.	

Source: Created by the author

3.7.2.8 Interactive Assessment Module

Storyboard No.: 8

Components: T (Text), G (Graphic), Ad (Audio), An (Animation), B (Button), O (Others)

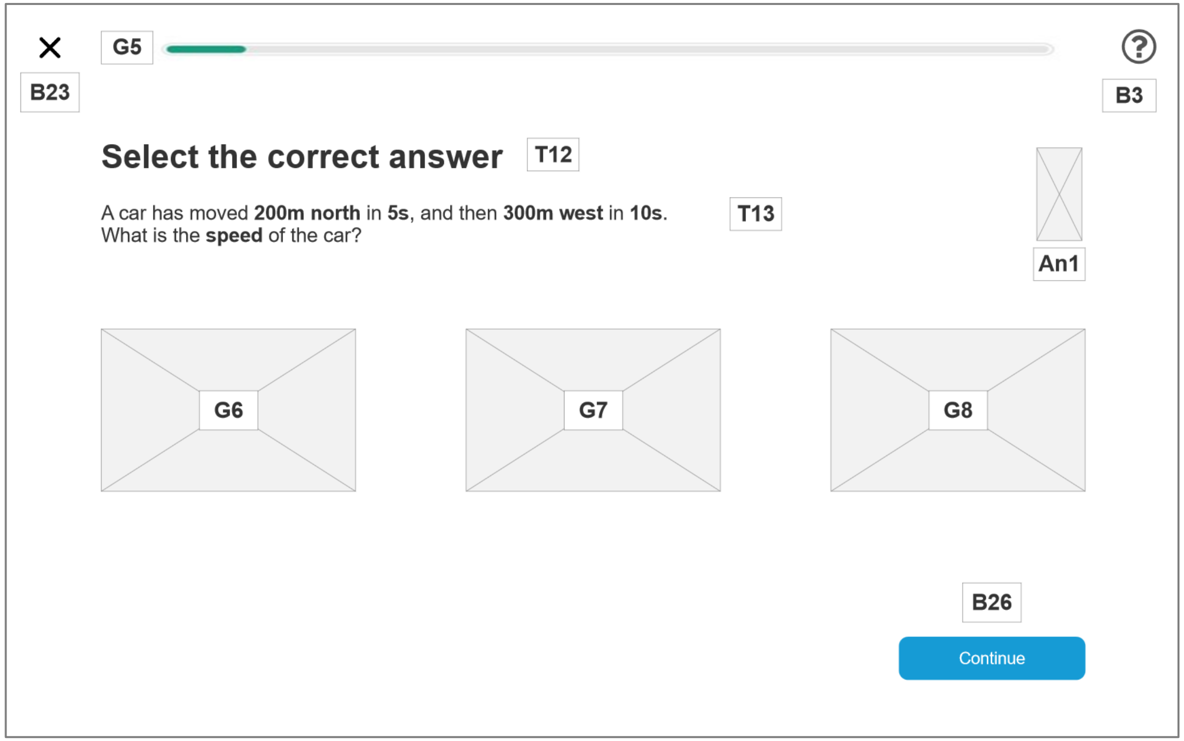
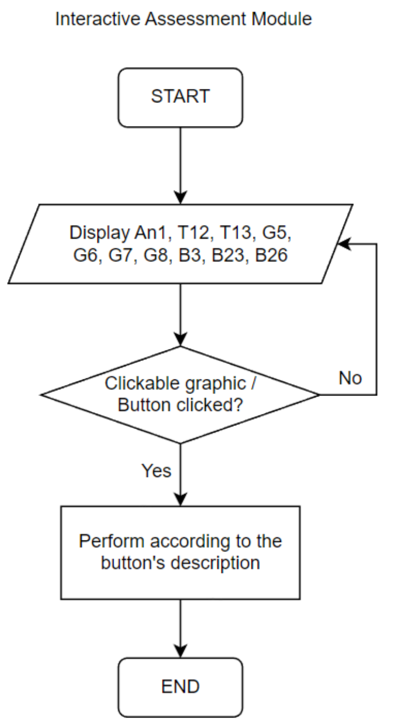


Figure 3.74: Interactive Assessment Module Storyboard

Source: Created by the author

Table 3.11: Description and flow diagram of interactive assessment module

Description	**Flow Diagram**
An1: An1 is the animation of virtual agent on tutorial module. **T12:** T12 is the instruction of this question. **T13:** T13 is one of the questions of the assessment. **G5:** G5 is the progress bar of the assessment. **G6:** G6 is the clickable graphic to select option 1. **G7:** G7 is the clickable graphic to select option 2. **G8:** G8 is the clickable graphic to select option 3. **B3:** B3 is the button for hint / help menu. **B23:** B23 is the button to withdraw from this assessment module. **B26:** B26 is the button to check the answer and continue to next question.	

Source: Created by the author

3.7.2.9 Hands-on Experiment Module with VR

Storyboard No.: 9

Components: T (Text), G (Graphic), Ad (Audio), An (Animation), B (Button), O (Others)

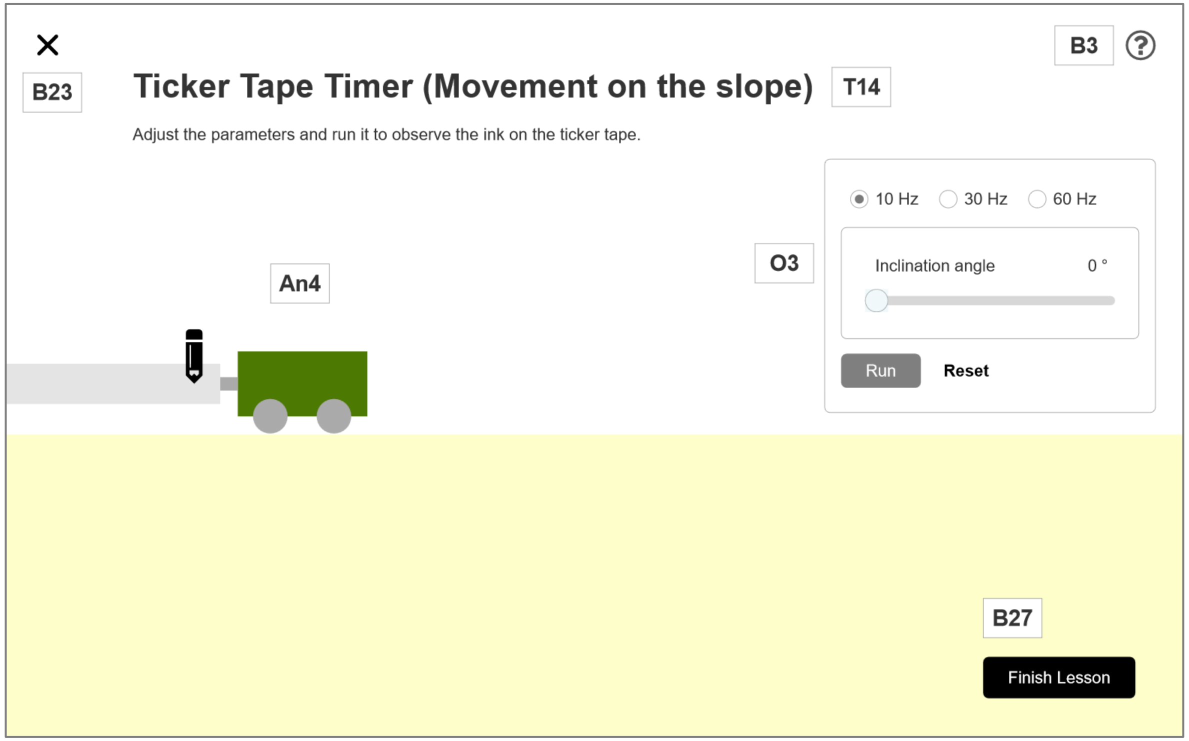
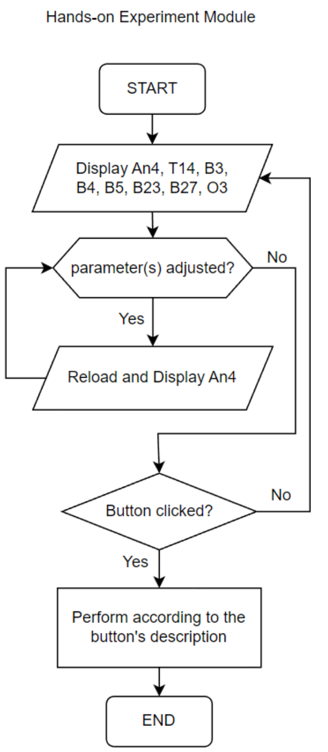


Figure 3.75: Hands-on Experiment Module with VR Storyboard

Source: Created by the author

Table 3.12: Description and flow diagram of hands-on experiment module with VR

Description	Flow Diagram
An4: An4 is the adjustable 3D animation in VR. **T14:** T14 is the title of this experiment. **B3:** B3 is the button for hint / help menu. **B23:** B23 is the button to withdraw from this experiment module. **B27:** B27 is the button to complete the experiment. **O3:** O3 is the region for user to adjust the parameters.	

Source: Created by the author

3.7.2.10 Gamified Elements Module

Storyboard No.: 10

Components: T (Text), G (Graphic), Ad (Audio), An (Animation), B (Button), O (Others)

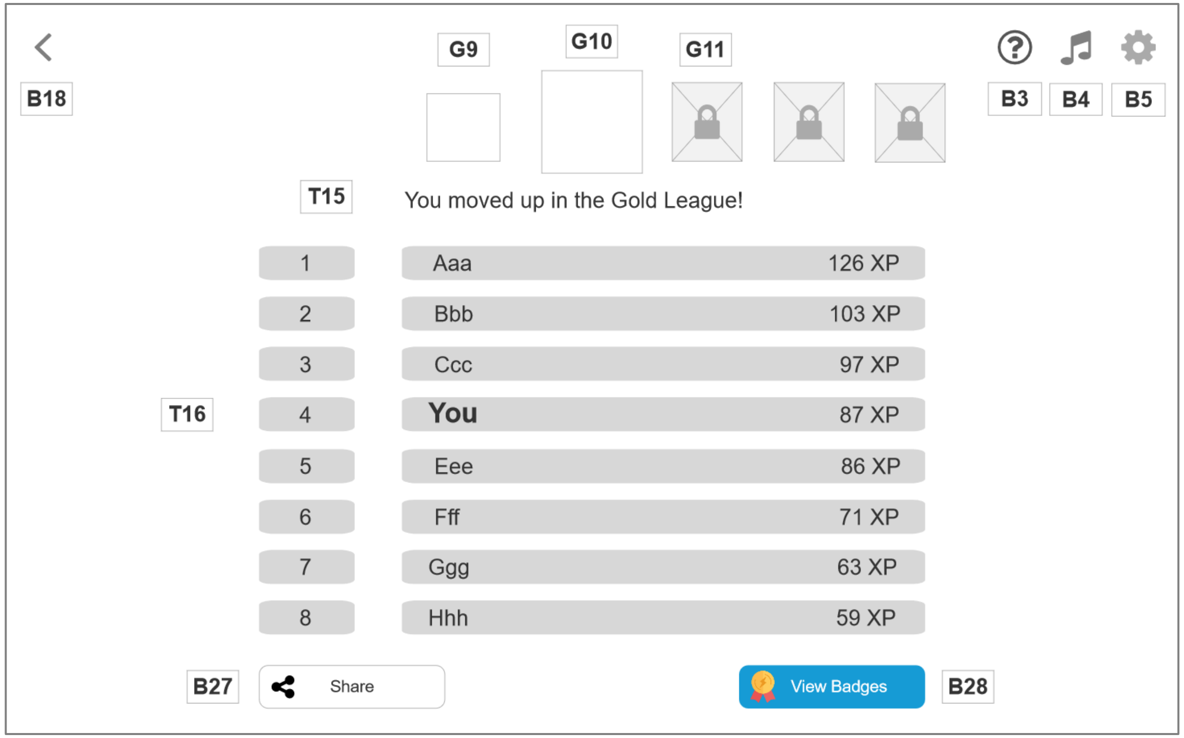
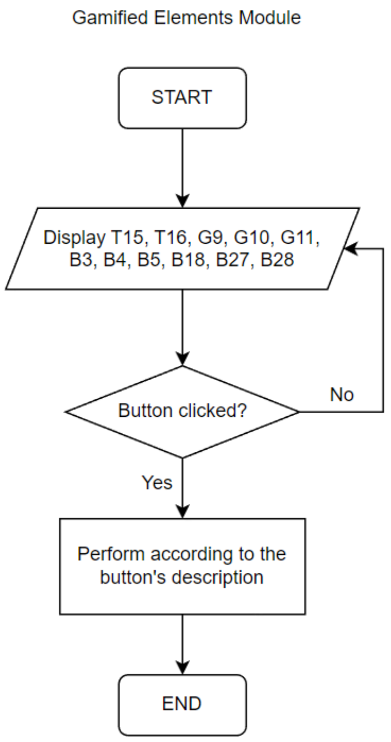


Figure 3.76: Gamified Elements Module Storyboard

Source: Created by the author

Table 3.13: Description and flow diagram of gamified elements module

Description	**Flow Diagram**
T15: T15 is the description for current league. **T16:** T16 is the text for leaderboard among students within the same class, with the user rank highlighted. **G9:** G9 is the badge for the previous achieved league. **G10:** G10 is the badge for current league. **G11:** G11 is the badges for the next few leagues, which are currently locked. **B3:** B3 is the button for hint / help menu. **B4:** B4 is the button to switch on or off the background music. **B5:** B5 is the button direct to user setting. **B18:** B18 is the button navigate to previous page. **B27:** B27 is the button to share user's current achievement. **B28:** B28 is the button navigate to view badges.	

Source: Created by the author

3.7.2.11 Collaborative Learning Space Module

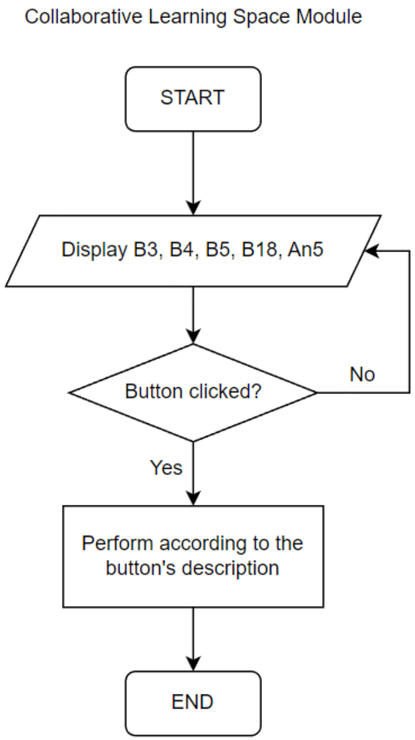
Storyboard No.: 11

Components: T (Text), G (Graphic), Ad (Audio), An (Animation), B (Button), O (Others)

Figure 3.77: Collaborative Learning Space Module Storyboard

Source: Created by the author

Table 3.14: Description and flow diagram of collaborative learning space module

<table>
<tr><th>Description</th><th>Flow Diagram</th></tr>
<tr><td>B3: B3 is the button for hint / help menu.
B4: B4 is the button to switch on or off the background music.
B5: B5 is the button direct to user setting.
B18: B18 is the button navigate to previous page.
An5: An5 is an animated virtual environment in which each user is represented as an animated character that can control their own movement and interact with other users in the same virtual space.</td><td>
</td></tr>
</table>

Source: Created by the author

3.8 Project Planning

Through the project planning process, two Gantt charts have been derived to outline the timelines and milestones for the two phases of the Final Year Project (FYP) – FYP1 and FYP2. FYP1 primarily focus on the analysis and design phases following the ADDIE model methodology. During this phase, the author delved into the analysis of requirements to identify the project scope, target audience, learning objectives, and design specifications. Additionally, the author developed detailed storyboards, prototypes, and system flow diagrams to visualize the instructional solution and gather feedback from stakeholders. Meanwhile, FYP2 encompassed the development, implementation, and evaluation phases of the project. This phase involved the actual creation of the educational application, integration of multimedia elements, software testing, deployment, and evaluation of the instructional solution's effectiveness. Both Gantt charts delineate the specific tasks, milestones, and deadlines associated with each stage, serving as roadmaps to guide the project's progression and ensure timely completion of key deliverables.

3.8.1 FYP1 Gantt Chart

FYP1 Project Schedule

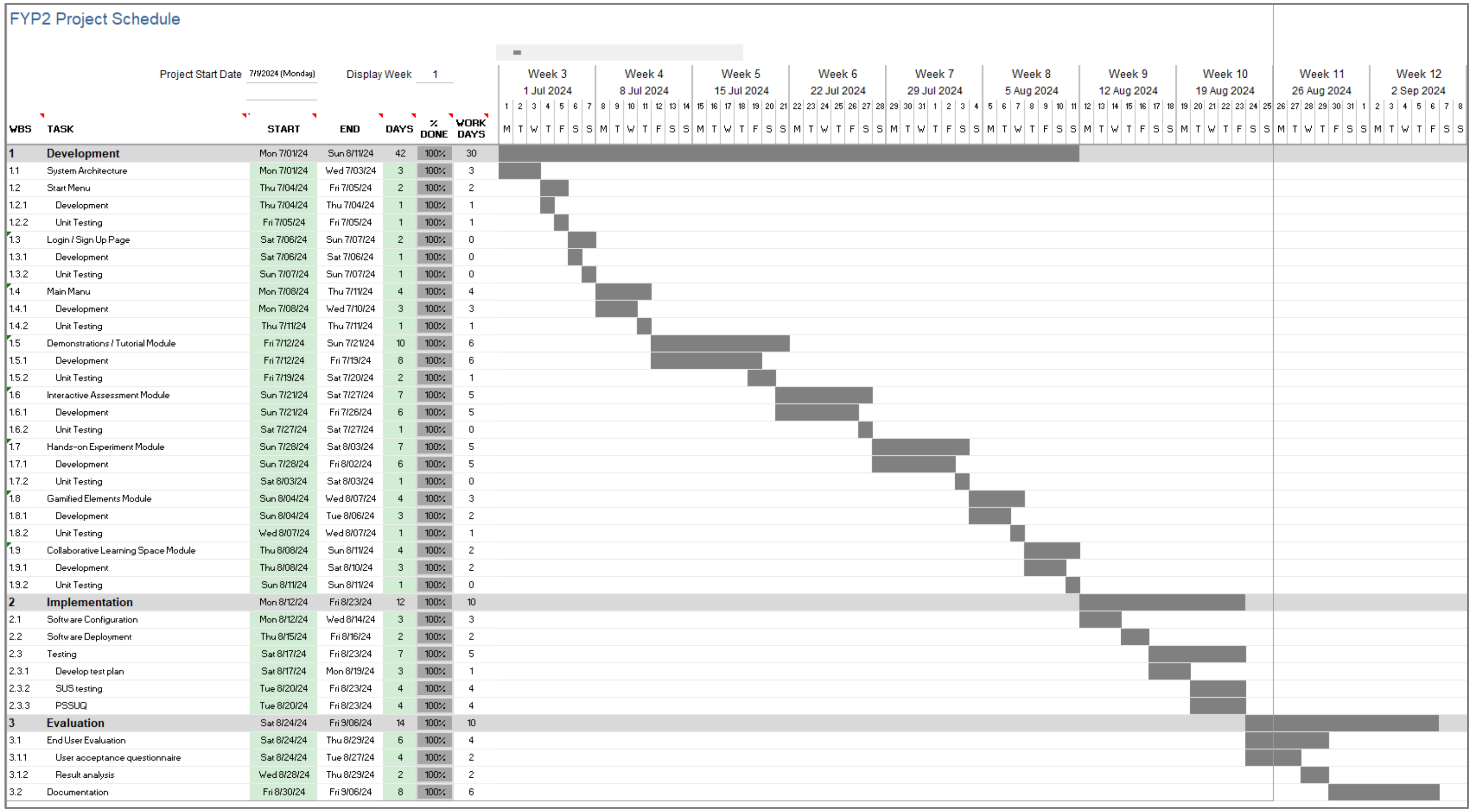
Project Start Date 2/19/2024 (Monday) Display Week 1

WBS	TASK	START	END	DAYS	% DONE	WORK DAYS
1	**Analysis**	Mon 2/19/24	Sun 3/17/24	28	100%	20
1.1	Problem Formulation	Mon 2/19/24	Fri 2/23/24	5	100%	5
1.1.1	Define problem statement	Mon 2/19/24	Tue 2/20/24	2	100%	2
1.1.2	Refine problem statement	Wed 2/21/24	Thu 2/22/24	2	100%	2
1.1.3	Finalise problem statement	Fri 2/23/24	Fri 2/23/24	1	100%	1
1.2	Solution Proposal	Sat 2/24/24	Sun 2/25/24	2	100%	0
1.3	Define Objective	Sun 2/25/24	Mon 2/26/24	2	100%	1
1.4	Literature Review	Mon 2/26/24	Sun 3/03/24	7	100%	5
1.4.1	Review on similar applications in Physics education	Mon 2/26/24	Wed 2/28/24	3	100%	3
1.4.2	Comparison of similar applications	Thu 2/29/24	Fri 3/01/24	2	100%	2
1.4.3	Project background study	Sat 3/02/24	Sun 3/03/24	2	100%	0
1.5	Project Scope	Mon 3/04/24	Sun 3/10/24	7	100%	5
1.5.1	Define project scope (5 modules)	Mon 3/04/24	Wed 3/06/24	3	100%	3
1.5.2	Refine project scope	Thu 3/07/24	Fri 3/08/24	2	100%	2
1.5.3	Finalise peoject scope	Sat 3/09/24	Sun 3/10/24	2	100%	0
1.6	Methodology	Mon 3/11/24	Thu 3/14/24	4	100%	4
1.6.1	Determine project methodology ADDIE Model	Mon 3/11/24	Mon 3/11/24	1	100%	1
1.6.2	Analysis Phase	Tue 3/12/24	Tue 3/12/24	1	100%	1
1.6.3	Design Phase	Tue 3/12/24	Tue 3/12/24	1	100%	1
1.6.4	Development Phase	Wed 3/13/24	Wed 3/13/24	1	100%	1
1.6.5	Implementation Phase	Wed 3/13/24	Wed 3/13/24	1	100%	1
1.6.6	Evaluation Phase	Thu 3/14/24	Thu 3/14/24	1	100%	1
1.7	System Requirements	Fri 3/15/24	Sun 3/17/24	3	100%	1
1.7.1	Software requirements	Fri 3/15/24	Sat 3/16/24	2	100%	1
1.7.2	Hardware requirements	Sun 3/17/24	Sun 3/17/24	1	100%	0
2	**Design**	Mon 3/18/24	Wed 4/17/24	31	100%	23
2.1	System Flow Diagram	Mon 3/18/24	Wed 3/20/24	3	100%	3
2.1.1	Design system flow diagram	Mon 3/18/24	Tue 3/19/24	2	100%	2
2.1.2	Refine system flow diagram	Wed 3/20/24	Wed 3/20/24	1	100%	1
2.2	Storyboard	Thu 3/21/24	Wed 4/03/24	14	100%	10
2.2.1	Design storyboard	Thu 3/21/24	Fri 3/29/24	9	100%	7
2.2.2	Refine storyboard	Sat 3/30/24	Wed 4/03/24	5	100%	3
2.3	Prototype	Thu 4/04/24	Wed 4/17/24	14	100%	10
2.3.1	Design prototype	Thu 4/04/24	Thu 4/11/24	8	100%	6
2.3.2	Refine prototype	Fri 4/12/24	Wed 4/17/24	6	100%	4

Figure 3.78: FYP1 Gantt Chart

Source: Created by the author

3.8.2 FYP2 Gantt Chart



WBS	TASK	START	END	DAYS	% DONE	WORK DAYS
1	**Development**	Mon 7/01/24	Sun 8/11/24	42	100%	30
1.1	System Architecture	Mon 7/01/24	Wed 7/03/24	3	100%	3
1.2	Start Menu	Thu 7/04/24	Fri 7/05/24	2	100%	2
1.2.1	Development	Thu 7/04/24	Thu 7/04/24	1	100%	1
1.2.2	Unit Testing	Fri 7/05/24	Fri 7/05/24	1	100%	1
1.3	Login / Sign Up Page	Sat 7/06/24	Sun 7/07/24	2	100%	0
1.3.1	Development	Sat 7/06/24	Sat 7/06/24	1	100%	0
1.3.2	Unit Testing	Sun 7/07/24	Sun 7/07/24	1	100%	0
1.4	Main Manu	Mon 7/08/24	Thu 7/11/24	4	100%	4
1.4.1	Development	Mon 7/08/24	Wed 7/10/24	3	100%	3
1.4.2	Unit Testing	Thu 7/11/24	Thu 7/11/24	1	100%	1
1.5	Demonstrations / Tutorial Module	Fri 7/12/24	Sun 7/21/24	10	100%	6
1.5.1	Development	Fri 7/12/24	Fri 7/19/24	8	100%	6
1.5.2	Unit Testing	Fri 7/19/24	Sat 7/20/24	2	100%	1
1.6	Interactive Assessment Module	Sun 7/21/24	Sat 7/27/24	7	100%	5
1.6.1	Development	Sun 7/21/24	Fri 7/26/24	6	100%	5
1.6.2	Unit Testing	Sat 7/27/24	Sat 7/27/24	1	100%	0
1.7	Hands-on Experiment Module	Sun 7/28/24	Sat 8/03/24	7	100%	5
1.7.1	Development	Sun 7/28/24	Fri 8/02/24	6	100%	5
1.7.2	Unit Testing	Sat 8/03/24	Sat 8/03/24	1	100%	0
1.8	Gamified Elements Module	Sun 8/04/24	Wed 8/07/24	4	100%	3
1.8.1	Development	Sun 8/04/24	Tue 8/06/24	3	100%	2
1.8.2	Unit Testing	Wed 8/07/24	Wed 8/07/24	1	100%	1
1.9	Collaborative Learning Space Module	Thu 8/08/24	Sun 8/11/24	4	100%	2
1.9.1	Development	Thu 8/08/24	Sat 8/10/24	3	100%	2
1.9.2	Unit Testing	Sun 8/11/24	Sun 8/11/24	1	100%	0
2	**Implementation**	Mon 8/12/24	Fri 8/23/24	12	100%	10
2.1	Software Configuration	Mon 8/12/24	Wed 8/14/24	3	100%	3
2.2	Software Deployment	Thu 8/15/24	Fri 8/16/24	2	100%	2
2.3	Testing	Sat 8/17/24	Fri 8/23/24	7	100%	5
2.3.1	Develop test plan	Sat 8/17/24	Mon 8/19/24	3	100%	1
2.3.2	SUS testing	Tue 8/20/24	Fri 8/23/24	4	100%	4
2.3.3	PSSUQ	Tue 8/20/24	Fri 8/23/24	4	100%	4
3	**Evaluation**	Sat 8/24/24	Fri 9/06/24	14	100%	10
3.1	End User Evaluation	Sat 8/24/24	Thu 8/29/24	6	100%	4
3.1.1	User acceptance questionnaire	Sat 8/24/24	Tue 8/27/24	4	100%	2
3.1.2	Result analysis	Wed 8/28/24	Thu 8/29/24	2	100%	2
3.2	Documentation	Fri 8/30/24	Fri 9/06/24	8	100%	6

Figure 3.79: FYP2 Gantt Chart

Source: Created by the author

CHAPTER 4

DEVELOPMENT

4.1 Overview

The Development chapter outlines the systematic process involved in building and implementing the learning application, marking a crucial stage in the ADDIE model. This phase focuses on translating the design into a functional system by integrating various components, modules, and features. Key tasks include coding the core functionalities and incorporating immersive technologies such as Mixed Reality (MR). Additionally, this chapter details the use of tools and technologies like Unity and the XR Interaction Toolkit, which were employed to create an engaging and intuitive user experience.

4.2 Development Process

The development process for the comprehensive Physics educational application, 'MetaPhysics', involved several key phases, each focused on creating a cohesive and interactive learning experience. The application integrates a range of modules aimed at fostering immersive learning and collaborative engagement. These components include the main menu, topic menus, tutorial module, hands-on experiments module, interactive assessments module, gamification elements module, and a collaborative learning space module. Each module was crafted to enhance the educational experience by incorporating advanced technologies and interactive features, supporting both individual and group learning.

The application was structured around two primary topics—Free Fall Motion and Force—each of which features three core modules: Tutorial, Hands-on Experiment, and Interactive Assessment. Gamification elements, such as badges, leaderboards, and quizzes, were introduced to increase user motivation and engagement. Additionally, the collaborative learning space allowed for group interactions, making the learning experience more social, interactive, and engaging.

4.2.1 Main Menu

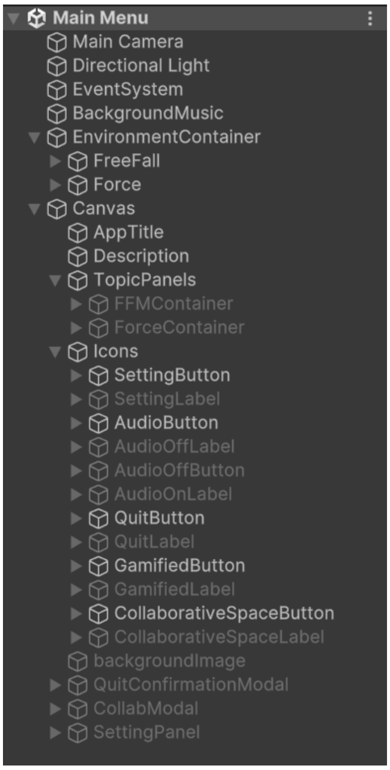


Figure 4.1: Main Menu scene's hierarchy

Figure 4.1 displays Unity's object hierarchy, a vital component of scene management in Unity. In this hierarchy, all game objects within a scene are listed, with each object potentially having multiple children. By default, a new scene contains two essential objects: the **Main Camera** and **Directional Light**. The **Event System**, which is automatically added when a UI object is created, facilitates event handling across various input methods such as keyboard, mouse, and touch, allowing developers to manage user interactions seamlessly.

Additionally, the **BackgroundMusic** object, which serves as an audio source, contains the background music for the application and plays automatically when the scene starts. This enhances user engagement by providing a continuous auditory experience.

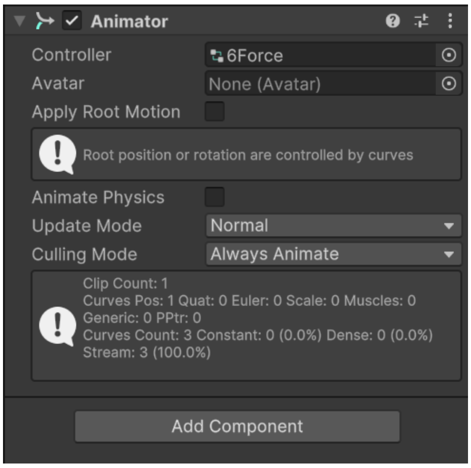


Figure 4.2: Animator component attached to Force object (chid of EnvironmentContainer)

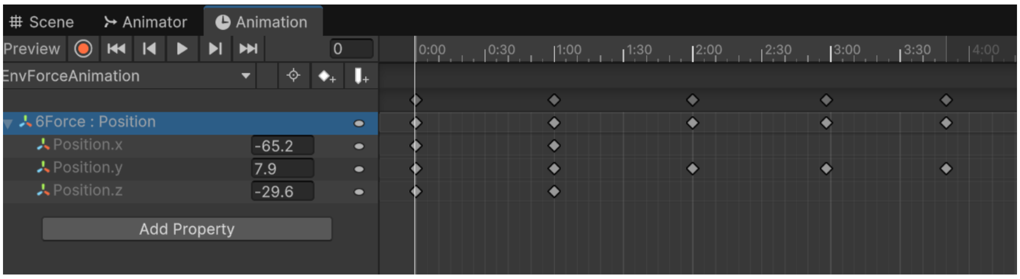


Figure 4.3: Animation of Force map

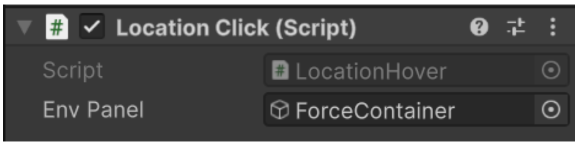


Figure 4.4: Location Hover Script attached to Force object (child of EnvironmentContainer)

```
using System;
using System.Collections.Specialized;
using UnityEngine;
using UnityEngine.SceneManagement;

public class LocationClick : MonoBehaviour
{
    private Renderer render;
    private Vector3 initialScale;
    public GameObject EnvPanel;

    void Start()
    {
        render = GetComponent<Renderer>();
    }

    private void OnMouseEnter()
    {
        increaseScale(true);
        EnvPanel.SetActive(true);
    }

    private void OnMouseExit()
    {
        increaseScale(false);
        EnvPanel.SetActive(false);
    }

    private void Awake()
    {
        initialScale = transform.localScale;
    }

    //Increase scale method
    private void increaseScale(bool status)
    {
        Vector3 finalScale = initialScale;

        //If status is tru increase scale
        if (status)
            finalScale = initialScale * 1.1f;

        transform.localScale = finalScale;
    }
}
```

Figure 4.5: Location Hover Script

Within the **EnvironmentContainer** object, two key 3D models, **FreeFall** and **Force**, represent the maps for each respective topic in the learning application. These models have a floating animation, designed to mimic the sensation of drifting in space. This effect is achieved by attaching an Animator component to the FreeFall and Force objects (Figure 4.2) and configuring the animation in the Animation panel to adjust the position of the objects over time (Figure 4.3).

Furthermore, when a user hovers over these maps, an interactive effect is triggered. Each map, assigned with the Location Hover script in the Inspector (Figure 4.4), enlarges by 0.1 in scale. This is accomplished using the Location Hover script (Figure 4.5), enhancing the interactivity of the UI. Simultaneously, a panel displaying the topic's description and a button to navigate to the topic menu appears, providing a clear call to action for the user to explore further.

Moreover, the **Canvas** object functions as the parent container for all UI elements, including text, images, and buttons. Every UI component must be a child of the canvas to ensure proper rendering and interaction within the user interface.

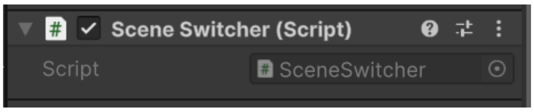


Figure 4.6: Scene Switcher script attached to Canvas object in inspector panel

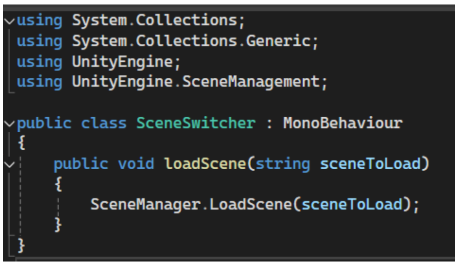


Figure 4.7: Scene Switcher script

In this particular scene, the Canvas object is assigned with the Scene Switcher script (Figure 4.6), which allows users to switch between various scenes within the application. The loadScene method, shown in Figure 4.7, is triggered upon specific button clicks, enabling smooth scene transitions.

Under the Canvas object, there are eight child objects in the Main Menu scene, including AppTitle, Description, TopicPanels, Icons, backgroundImage, QuitConfirmationModal, CollabModal, and SettingPanel. The objects displayed in darker colors indicate that they are inactive by default and will only be displayed when activated.

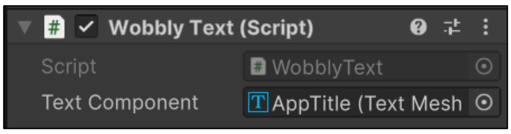


Figure 4.8: "Wobbly Text" script attached to AppTitle object in inspector panel

```
using UnityEngine;
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using TMPro;

public class WobblyText : MonoBehaviour
{
    public TMP_Text textComponent;

    void Update()
    {
        textComponent.ForceMeshUpdate();
        var textInfo = textComponent.textInfo;

        for (int i = 0; i < textInfo.characterCount; i++)
        {
            var charInfo = textInfo.characterInfo[i]; ;
            if (!charInfo.isVisible)
            {
                continue;
            }

            var verts = textInfo.meshInfo[charInfo.materialReferenceIndex].vertices;

            for (int j = 0; j < 4; j++)
            {
                var orig = verts[charInfo.vertexIndex + j];
                verts[charInfo.vertexIndex + j] = orig +
                    new Vector3(0, Mathf.Sin(Time.time * 1f + orig.x * 0.01f) * 10f, 0);
            }
        }

        for (int i = 0; i < textInfo.meshInfo.Length; ++i)
        {
            var meshInfo = textInfo.meshInfo[i];
            meshInfo.mesh.vertices = meshInfo.vertices;
            textComponent.UpdateGeometry(meshInfo.mesh, i);
        }
    }
}
```

Figure 4.9: Wobbly Text script

Figure 4.10: Wobbly text effect

The **AppTitle** and **Description** objects are assigned the WobblyText script in their Unity Inspector panels (Figure 4.8), which applies a dynamic, wavy-like animation to the text (Figure 4.9). This effect adds a lively and engaging visual aesthetic to the application's interface (Figure 4.10).

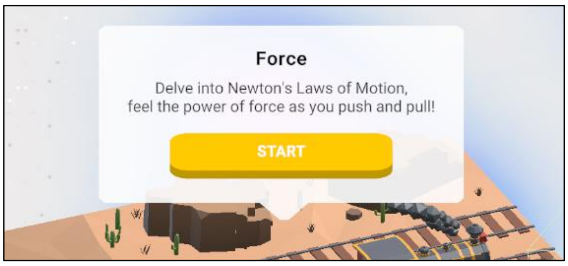


Figure 4.11: Force's Topic Panel

Additionally, within the **TopicPanels** object, there are two panels corresponding to the topics of Force and Free Fall Motion. Each panel includes a brief description of the topic and a button that allows the user to navigate to the specific topic's menu scene, as outlined in Section 4.2.2. The topic menu provides further options, allowing the user to access tutorials, hands-on experiments, and interactive assessments for each topic. These panels remain inactive when the scene starts and are only displayed when the user hovers over the 3D model of the corresponding map.

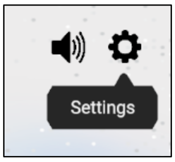


Figure 4.12: Setting Label

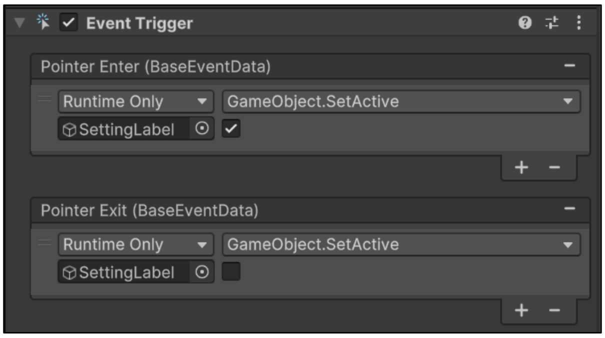


Figure 4.13: Event Trigger in SettingButton

Within the **Icons** object under the Canvas, there are five active buttons or icons: **SettingButton**, **AudioButton**, **QuitButton**, **GamifiedButton**, and **CollaborativeSpaceButton**. Each button has a specific purpose and is paired with a label that appears when the user hovers over the button. Figure 4.12 demonstrates an example of hovering over the SettingButton. As illustrated in Figure 4.13, the Event Trigger component in SettingButton activates the SettingLabel object when the mouse enters, and deactivates it when the mouse exits the button, providing a clear, responsive user experience.

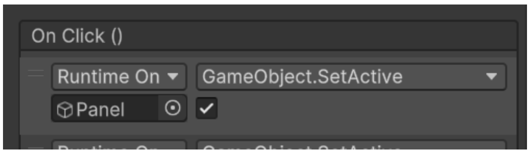


Figure 4.14: onClick function in SettingButton object

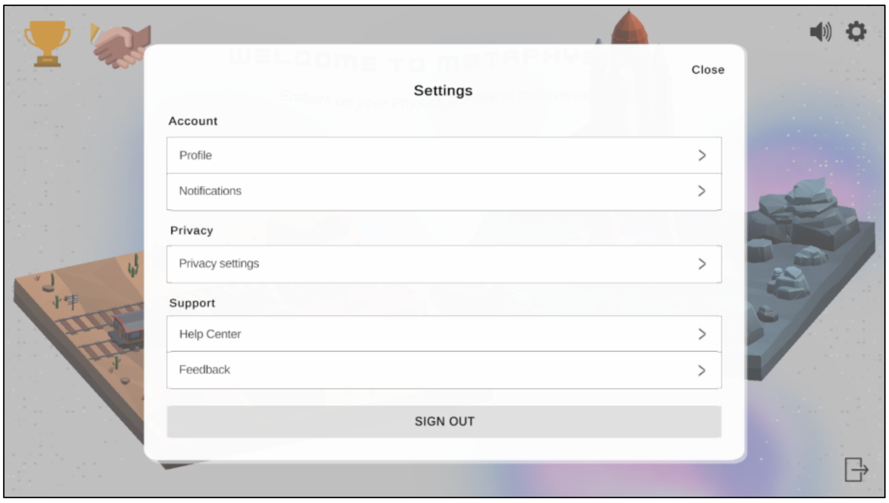


Figure 4.15: SettingPanel object

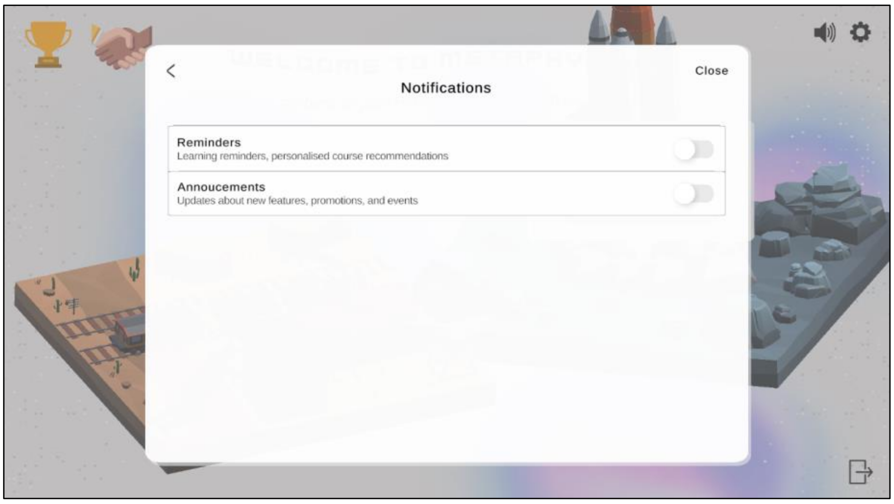


Figure 4.16: Notifications setting panel

SettingButton: This button opens the SettingPanel, which allows users to modify various settings like profile, notifications, privacy settings, and support preferences (Figure 4.14). When clicked, the SettingPanel becomes active via the onClick function (Figure 4.15), granting access to a range of customizable application settings. An example of the Notification Setting Panel is shown in Figure 4.16.

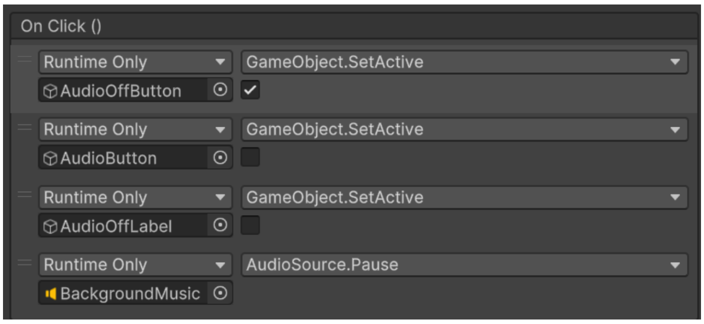


Figure 4.17: onClick function setting in AudioButton

Figure 4.18: Audio off icon with Audio off label

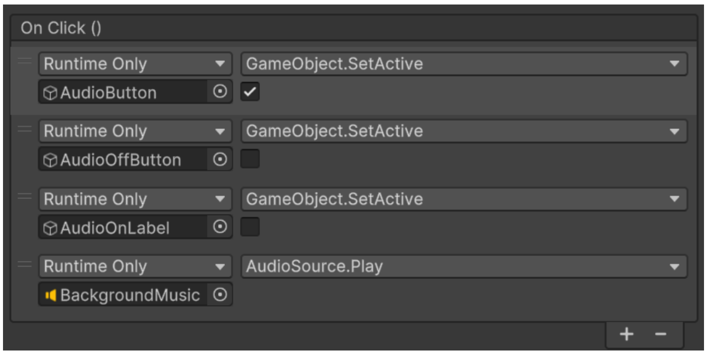


Figure 4.19: onClick function setting in AudioOffButton

AudioButton: The AudioButton allows users to pause or resume the background music of the application. When clicked, it pauses the background music and activates the AudioOffButton to indicate that the audio has been turned off (Figure 4.17). Users can hover over this button to see the Audio On label (Figure 4.18), and by clicking the AudioOffButton, the background music resumes via the onClick function, as shown in Figure 4.19.

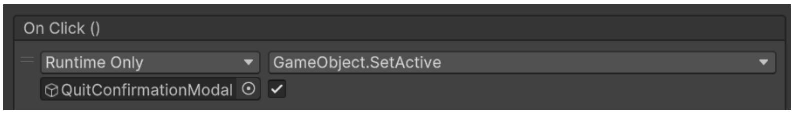


Figure 4.20: onClick function setting in QuitButton

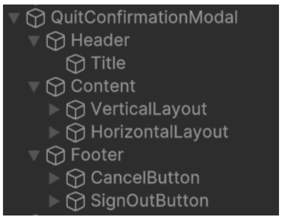


Figure 4.21: QuitConfirmationModal object

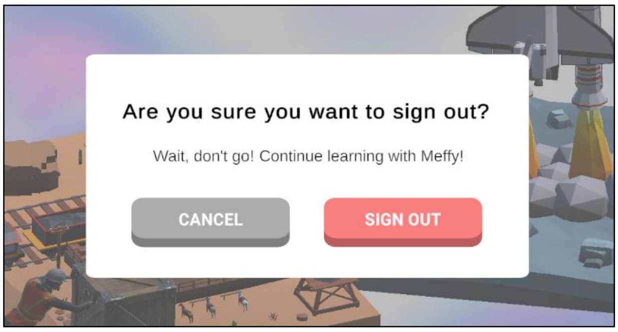


Figure 4.22: Quit Confirmation Modal

QuitButton: This button triggers the QuitConfirmationModal through an onClick function (Figure 4.20). As depicted in Figure 4.21, this modal contains a title, description, and buttons that allow users to confirm or cancel their decision to quit the application. Figure 4.22 showcases the QuitConfirmationModal with all relevant elements displayed upon clicking the QuitButton.

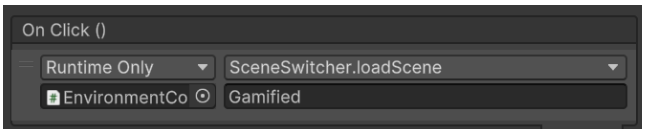


Figure 4.23: onClick function in GamifiedButton

GamifedButton: Clicking this button navigates the user to the Gamified scene, which houses the gamification elements module (Section 4.2.6). This navigation is managed by the onClick function set in the GamifiedButton (Figure 4.23), which calls the loadScene function in the SceneSwitcher script (Figure 4.7). This script, attached to the EnvironmentContainer object, efficiently handles scene transitions.

Figure 4.24: onClick function in CollaborativeSpaceButton

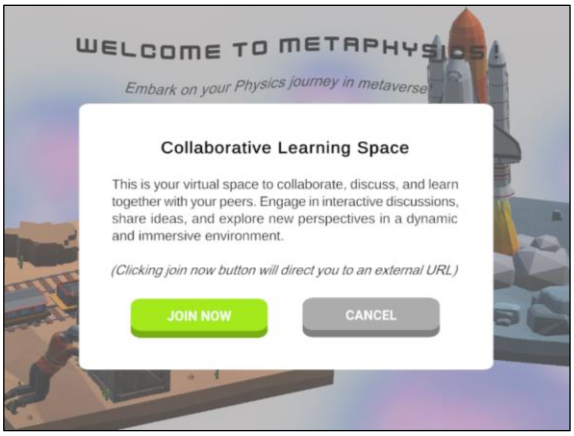


Figure 4.25: CollabModal

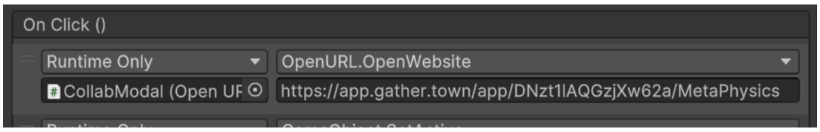


Figure 4.26: onClick function in CollaborativeSpaceButton

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class OpenURL : MonoBehaviour
{
    public void OpenWebsite(string url)
    {
        Application.OpenURL(url);
    }
}
```

Figure 4.27: OpenURL script

CollaborativeSpaceButton: This button activates the CollabModal object through the onClick function (Figure 4.24). Once clicked, the Collaborative Space Confirmation Modal appears, as shown in Figure 4.25. This modal prompts the user with a title and description, along with buttons that perform different actions. The JOIN NOW button navigates the user to the Collaborative Learning Space module (Section 4.2.7), an external URL linking to Gather.Town. This is achieved through the onClick function set in the CollaborativeSpaceButton (Figure 4.26), which calls the OpenWebsite function in the OpenURL script (Figure 4.27) attached to the CollabModal object.

Figure 4.28: Main Menu UI

Figure 4.28 shows the Main Menu UI of the application.

4.2.2 Topic Menu

The learning application encompasses two primary topics: Free Fall Motion and Force. Each topic is structured into three distinct modules: Tutorial, Hands-on Experiment, and Interactive Assessment.

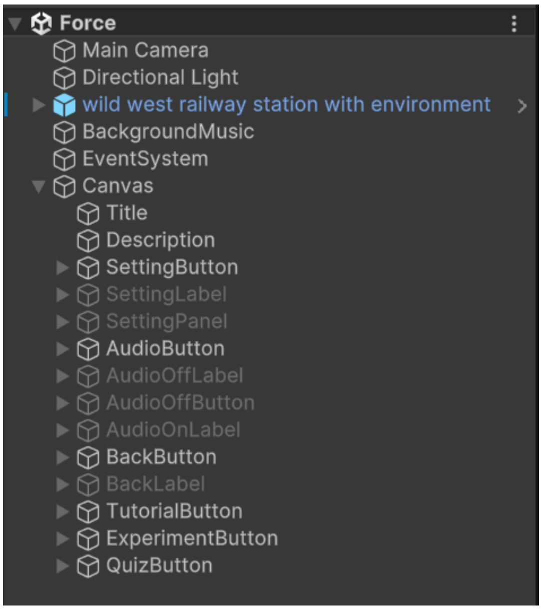


Figure 4.29: Topic Menu Scene's Hierarchy

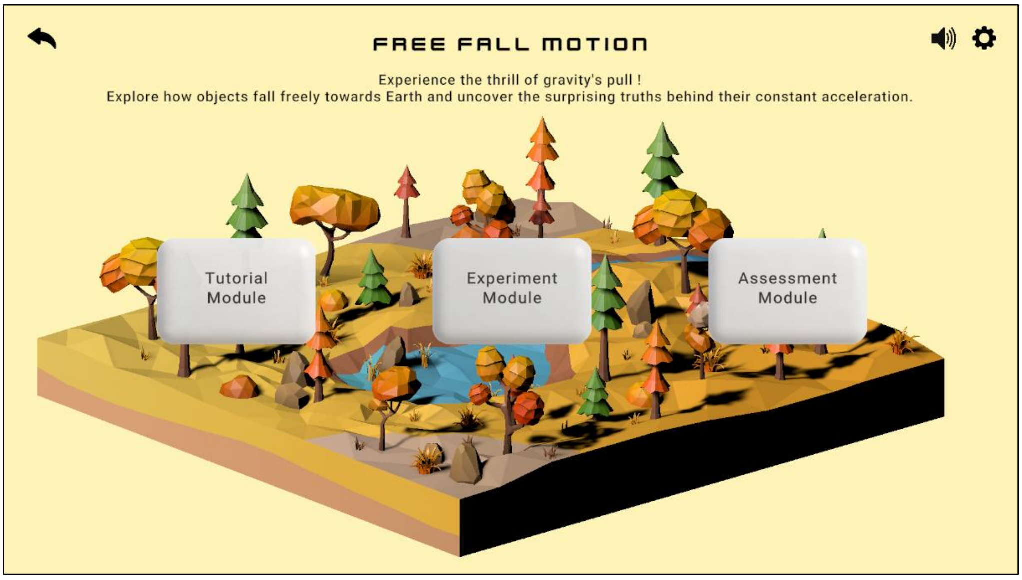


Figure 4.30: Free fall motion topic's menu UI

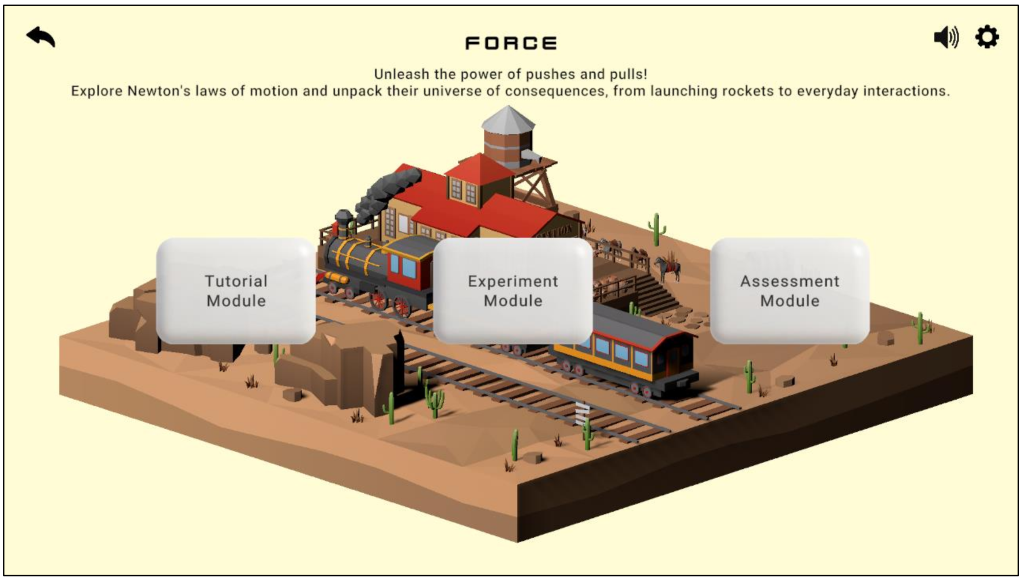


Figure 4.31: Force topic's menu UI

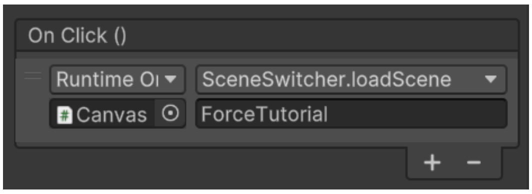


Figure 4.32: onClick function in TutorialButton

The menu for both topics follows a consistent hierarchical layout, as illustrated in Figure 4.29. Figures 4.30 and 4.31 depict the menus for the Force and Free Fall Motion topics, respectively. Like the main menu, each topic menu includes:

- Settings Button: For adjusting application settings.
- Audio Button: To manage sound settings.
- Back Button: Allows users to easily navigate back to the main menu.

The central area of each topic menu features three buttons, corresponding to the Tutorial, Experiment, and Assessment modules. Clicking these buttons directs users to the appropriate module for the selected topic. This navigation is managed by the onClick function of each button, which employs the loadScene method from the SceneSwitcher script attached to the Canvas object (e.g., as demonstrated in Figure 4.31).

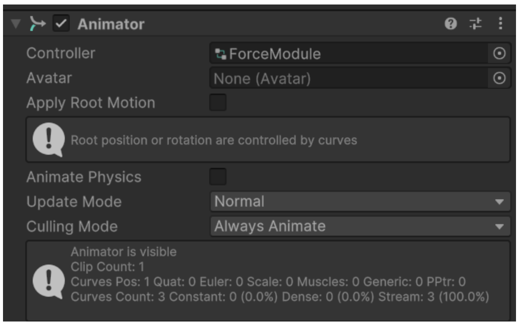


Figure 4.33: Animator component in Force environment 3D model's Inspector

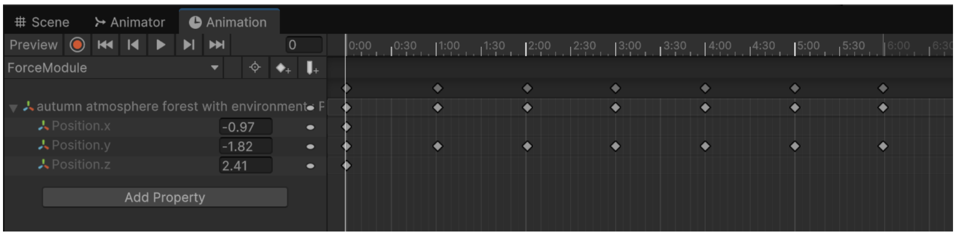


Figure 4.34: Force environment 3D model's animation panel

To enhance the visual experience, the background environment's 3D model includes a dynamic animation. This animation adjusts the Y position of the model to simulate a gradual upward and downward movement, creating a relaxing floating effect, as shown in Figure 4.34.

4.2.3 Demonstrations / Tutorial Module

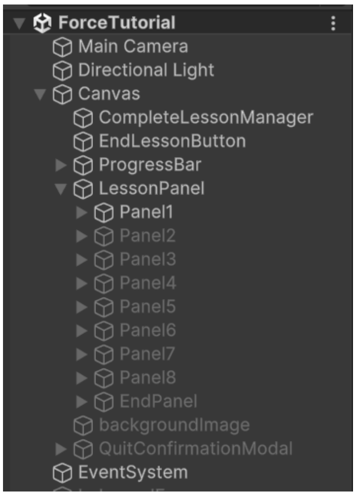


Figure 4.35: Tutorial Module's hierarchy

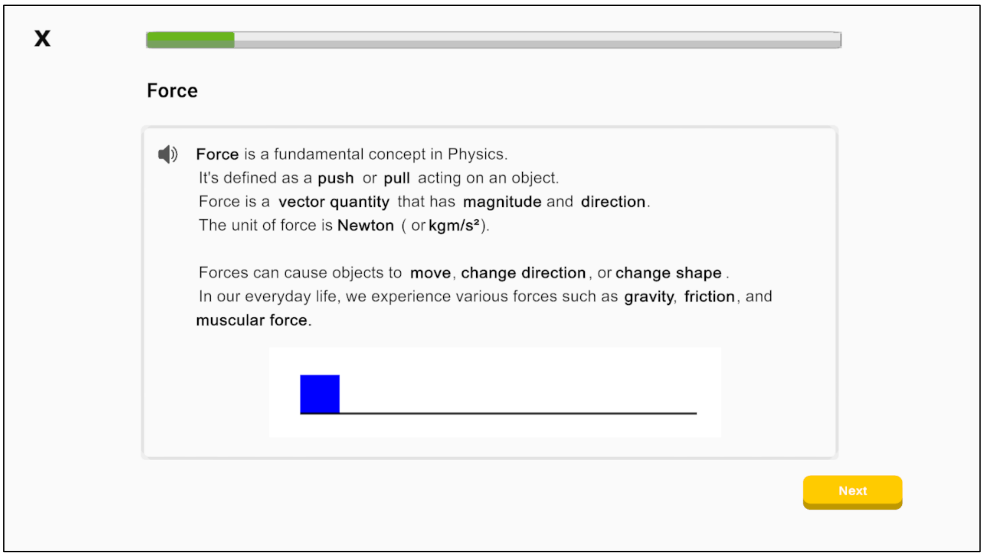


Figure 4.36: Example of tutorial module (Force topic)

Figure 4.35 illustrates the object hierarchy for the Tutorial module within the Force topic. This module includes two tutorial scenes: FreeFallTutorial and ForceTutorial, each adhering to a similar hierarchy structure and user interface design, as depicted in Figure 4.36.

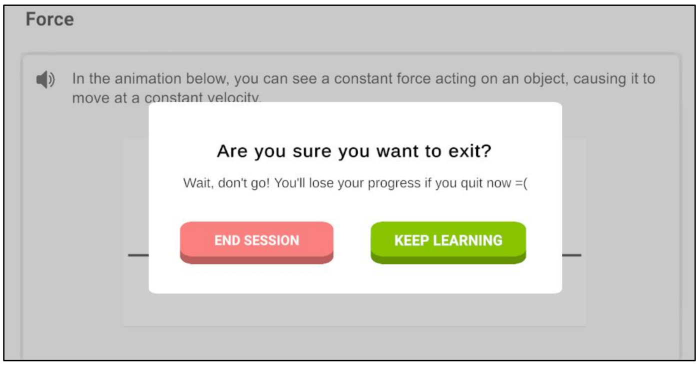


Figure 4.37: QuitConfirmationModal

The **EndLessonButton** triggers the activation of the **QuitConfirmationModal** when clicked, as depicted in Figure 4.37. This modal includes:

- **Title**: Displays a confirmation message.
- **Description**: Encourages users to complete the tutorial with a motivational message.
- **End Session Button**: Redirects users back to the topic menu (Section 4.2.2).
- **Keep Learning Button**: Closes the modal and allows users to continue their tutorial.

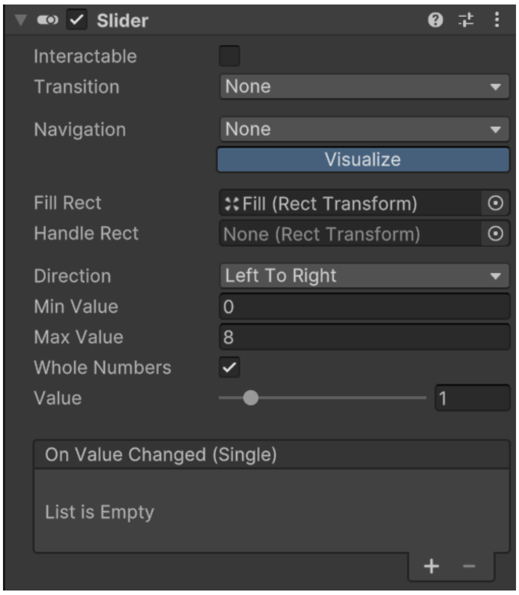


Figure 4.38: Slider component of ProgressBar object

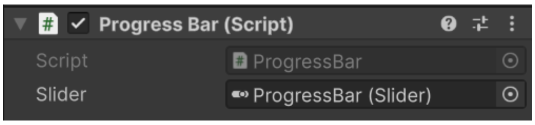


Figure 4.39: Progress Bar script attached to ProgressBar object

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.UI;

public class ProgressBar : MonoBehaviour
{

    public Slider slider;

    public void setProgress(int progress)
    {
        slider.value = progress;
    }
}
```

Figure 4.40: Progress Bar script

The progress bar serves as an indicator of the user’s advancement through the tutorial, using a slider component, as demonstrated in Figure 4.38. The Max Value is set to the total number of learning panels within the topic. The ProgressBar script, attached to the **ProgressBar** object, manages the update of the progress bar based on the user's current position in the tutorial (see Figure 4.40). This script features a setProgress method to adjust the fill level according to the learning panel the user is on.

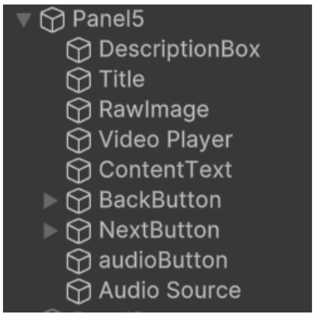


Figure 4.41: The children of one of the panel in LessonPanel object

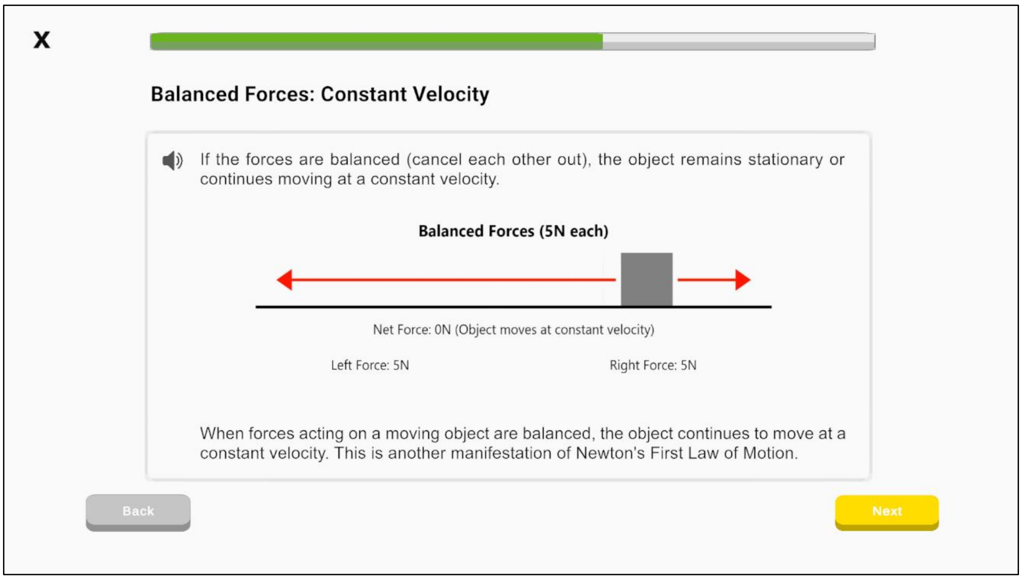


Figure 4.42: Panel5 UI

Each **LessonPanel** encompasses a range of content elements, such as texts, audio sources, images, video players, and buttons. Figure 4.41 displays the children of an example panel within the LessonPanel object, with the UI elements illustrated in Figure 4.42.

The tutorial module is designed to be interactive, incorporating narrations, images, videos, animations, and AR features to facilitate a comprehensive learning experience.

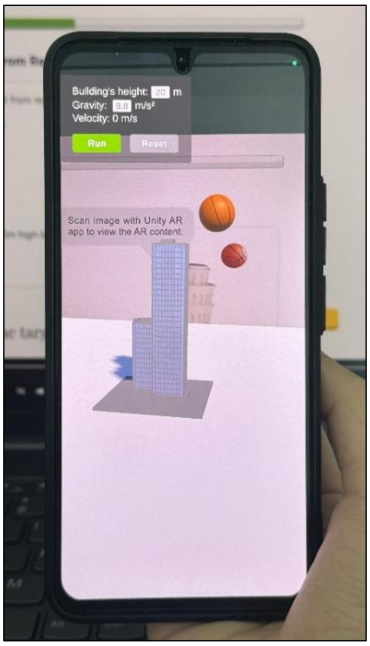


Figure 4.43: AR features activated by scanning with an external device

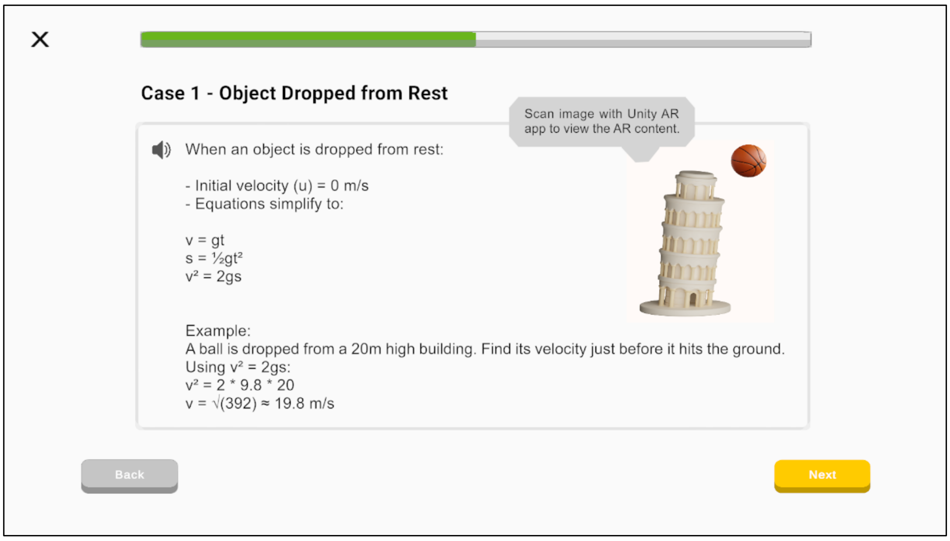


Figure 4.44: Target image used to trigger the AR free fall motion simulation

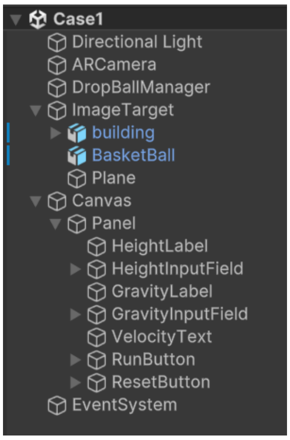


Figure 4.45: Hierarchy of the AR scene

The development of the AR features above focuses on illustrating the concept of free fall motion through an interactive experience. As shown in Figure 4.43, the AR feature is activated when an external device scans the target image depicted in Figure 4.44. Once scanned, the AR scene is initiated, as outlined in the hierarchy presented in Figure 4.45. The hierarchy includes several key components: the AR camera, which captures and renders the augmented scene; the image target GameObject, which contains the 3D models of the building and the ball, serving as the primary visual elements for demonstrating the free fall motion; and the DropBallManager GameObject, responsible for managing the "DropBallManager" script (Figure 4.46 to 4.48) that handles the physics-based drop interaction.

Additionally, a Canvas GameObject is implemented to manage the user interface (UI) elements. These include displays for real-time data such as velocity, and displays for height and gravity, which users can adjust, as well as interactive buttons for running and resetting the scene.

```
using UnityEngine;
using UnityEngine.UI;
using TMPro;
using UnityEngine.SceneManagement;
Unity Script (1 asset reference) | 0 references
public class DropBallManager : MonoBehaviour
{
    public Rigidbody ballRigidbody;
    public TextMeshProUGUI velocityText;
    public float assumedBuildingHeight = 20.0f;
    public float actualDropHeight = 0.3f;
    public Button dropButton;
    public Button resetButton;
    public float bounceForce = 5f; // Adjust this value to control bounce strength
    public TMP_InputField heightInputField;
    public TMP_InputField gravityInputField;

    private bool isFalling = false;
    private float distanceFallen = 0f;
    private float gravity = 9.8f;  // Acceleration due to gravity
    private Vector3 initialPosition;
    private float scaleFactor;
    Unity Message | 0 references
    void Start()
    {
        initialPosition = ballRigidbody.transform.position; // Save the initial position to reset later
        // Initially freeze the ball in place (no gravity yet)
        ballRigidbody.isKinematic = true;  // Disable physics interaction initially
        ballRigidbody.useGravity = false; // Initially freeze the ball in place
        ballRigidbody.linearVelocity = Vector3.zero;
        // Assign button click events
        dropButton.onClick.AddListener(DropBall);
        resetButton.onClick.AddListener(ResetScene);
        // Initialize velocity text
        velocityText.text = "Velocity: 0 m/s";

        heightInputField.text = assumedBuildingHeight.ToString();
        gravityInputField.text = gravity.ToString();

        UpdateScaleFactor();
    }
```

Figure 4.46: Drop Ball Manager script (Part A)

```csharp
void Update()
{
    if (isFalling)
    {
        // Calculate the distance fallen along Z-axis
        distanceFallen = initialPosition.z - ballRigidbody.transform.position.z;
        // Only update velocity if the distance is non-negative (to avoid NaN values)
        if (distanceFallen >= 0)
        {
            float velocity = Mathf.Sqrt(2 * gravity * distanceFallen * scaleFactor);
            velocityText.text = "Ball's velocity: " + velocity.ToString("F2") + " m/s";
        }
        else
        {
            velocityText.text = "Ball's velocity: 0 m/s";
        }
    }
}

2 references
void UpdateScaleFactor()
{
    scaleFactor = assumedBuildingHeight / actualDropHeight;
}

1 reference
public void ApplyCustomSettings()
{
    if (float.TryParse(heightInputField.text, out float newHeight) && newHeight > 0)
    {
        assumedBuildingHeight = newHeight;
    }

    if (float.TryParse(gravityInputField.text, out float newGravity) && newGravity > 0)
    {
        gravity = newGravity;
    }

    UpdateScaleFactor();
}
1 reference
public void DropBall()
{
    ApplyCustomSettings();

    ballRigidbody.isKinematic = false;  // Enable physics interaction
    ballRigidbody.AddForce(new Vector3(0, 0, -gravity), ForceMode.Acceleration);  // Gravity along Z-axis
    isFalling = true; // Mark the ball as falling
}
```

Figure 4.47: Drop Ball Manager script (Part B)

```csharp
Unity Message | 0 references
public void OnCollisionEnter(Collision collision)
{
    if (collision.gameObject.tag == "Ground")
    {
        // Stop the ball when it hits the ground
        ballRigidbody.linearVelocity = Vector3.zero;
        isFalling = false;
    }
}
1 reference
public void ResetScene()
{
    SceneManager.LoadScene(SceneManager.GetActiveScene().name);
}
}
```

Figure 4.48: Drop Ball Manager script (Part C)

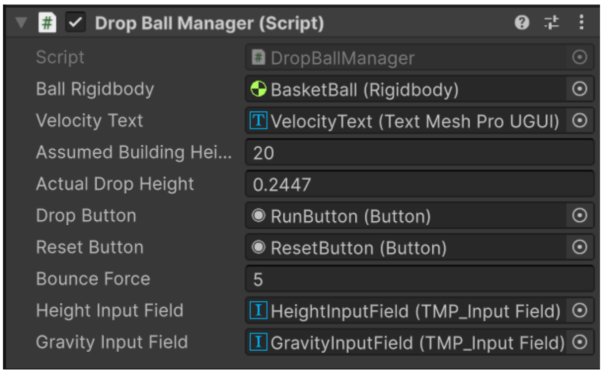


Figure 4.49: Drop Ball Manager script attached to the Drop Ball Manager GameObject

The main function of the DropBallManager script as shown in Figure 4.46 to 4.48 is to simulate a free fall experiment where the user can drop a ball from a user-defined height and observe its motion under gravity. The script manages the following key functionalities:

1. **Customizable Fall Parameters**: The user can set the height from which the ball drops and the gravitational force using input fields. These parameters can be adjusted to simulate different environments or scenarios.
2. **Ball Drop Simulation**: When the "Drop" button is clicked, the ball is released from its initial position, and gravity is applied, causing it to fall. The script calculates and applies the gravitational force, simulating real-world Physics based on the provided input.
3. **Real-Time Velocity Display**: As the ball falls, the script continuously calculates and updates the ball's velocity using the equation: $v^2 = u^2 + 2gs$ (where *u* is the initial velocity, which is 0, *g* is gravity, and *s* is the distance fallen). The calculated velocity, *v* is displayed in the user interface in real time.
4. **Collision Detection**: The script detects when the ball collides with the ground (an object tagged as "Ground") and stops the fall by setting the velocity to zero and halting the velocity update.
5. **Scene Reset**: A "Reset" button allows the user to reset the simulation to its initial state, restoring the ball to its original position and resetting all UI elements and inputs, readying the experiment for another run.

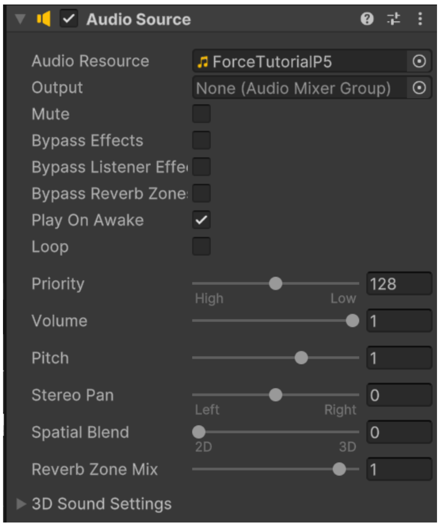


Figure 4.50: Audio Source component in the Audio Source object in Panel5

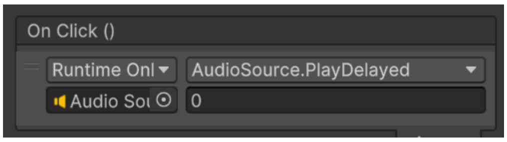


Figure 4.51: onClick function in the audioButton object

The audio narrations for each panel are stored as MP3 files within the Audio Resource component of the Audio Source object (refer to Figure 4.50). The audioButton enables users to replay the narration from the beginning using the PlayDelayed method (as shown in Figure 4.51).

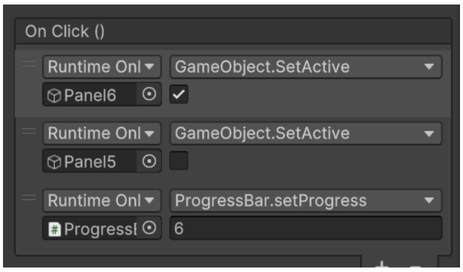


Figure 4.52: onClick function of NextButton in Panel5 object

Each panel includes both Back and Next buttons, except for the first panel, which features only a Next button, and the last panel, which has a Finish Lesson button instead of the Next button. The Next button functionality, for instance in Panel 5 (Figure 4.52), activates Panel 6 while deactivating itself. It also updates the progress bar to reflect the next panel number using the setProgress method.

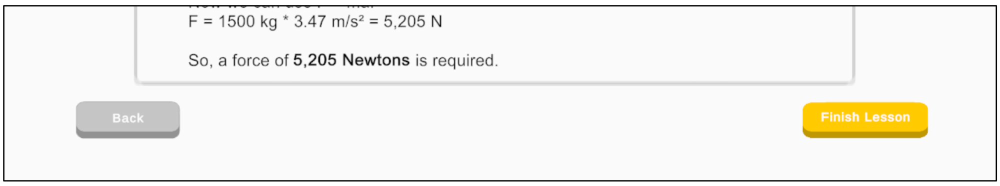


Figure 4.53: Buttons in the last learning panel

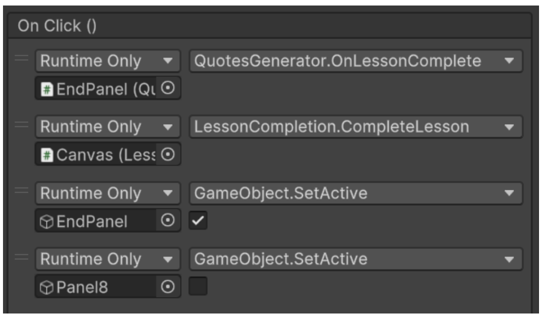


Figure 4.54: onClick function of the 'Finish Lesson' button in the last learning panel

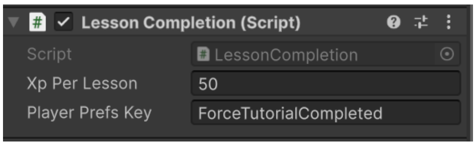


Figure 4.55: Lesson Completion script attached to the CompleteLessonManager object

```
using System.Diagnostics;
using UnityEngine;

public class LessonCompletion : MonoBehaviour
{
    public int xpPerLesson = 40;
    public string playerPrefsKey;

    public void CompleteLesson()
    {
        int totalXP = PlayerPrefs.GetInt("TotalXP", 0);
        if (!string.IsNullOrEmpty(playerPrefsKey))
        {
            PlayerPrefs.SetInt(playerPrefsKey, 1); // Set the key to 1 (true)
            PlayerPrefs.Save(); // Save the PlayerPrefs
        }
        totalXP += xpPerLesson;
        PlayerPrefs.SetInt("TotalXP", totalXP);
        PlayerPrefs.Save();
    }
}
```

Figure 4.56: Lesson Completion script

Upon clicking the Finish Lesson button in the final panel (Figure 4.53), the onClick function of it (Figure 4.54) will trigger the following actions:

1. **Quotes Generator**: Generates and displays congratulatory and motivational quotes on the ending panel.
2. **LessonCompletion** script (see Figure 4.56): Updates the total XP and marks the tutorial as complete (playerPrefsKey), which is then used to grant badges in the gamification module (section 4.2.6). The playerPrefsKey and XP values are configured in the CompleteLessonManager object's inspector panel (Figure 4.55).

Figure 4.57: EndPanel's children

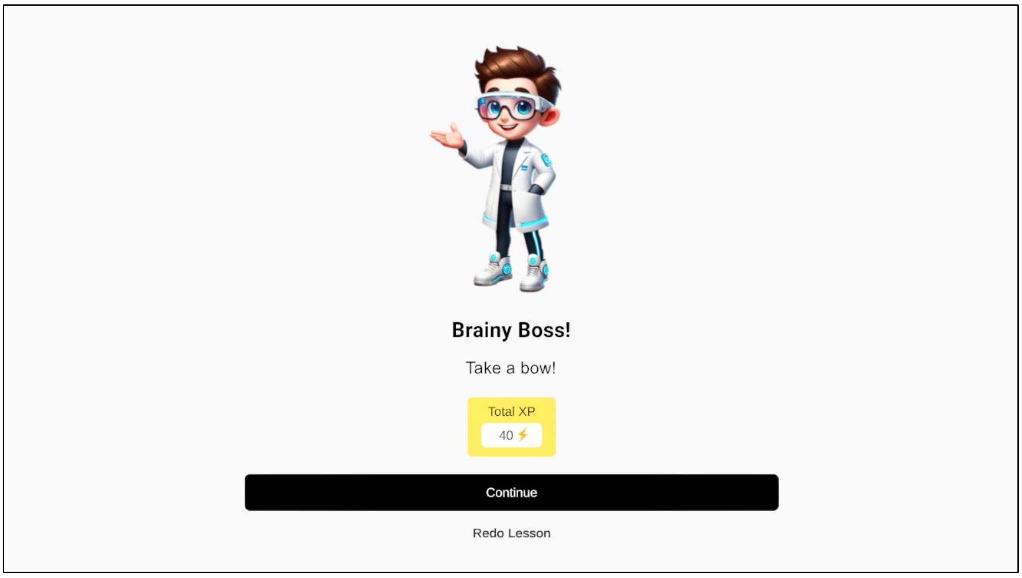


Figure 4.58: EndPanel UI

After clicking the ‘Finish Lesson’ button in the last learning panel, an ending panel as shown in Figure 4.58 will be displayed. Figure 4.57 illustrates the components within the ending panel, which include a character image, motivational quotes designed to encourage users, an XP displayer featuring a bounce animation that highlights the XP earned during the lesson, and an audio source providing sound effects for the XP displayer. Additionally, the panel contains buttons for continuing to the next section or redoing the lesson.

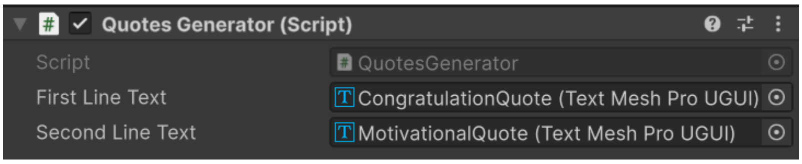


Figure 4.59: Quotes Generator script attached to the EndPanel object

```
using UnityEngine;
using UnityEngine.UI;
using System.Collections.Generic;
using TMPro;

public class QuotesGenerator : MonoBehaviour
{
    public TextMeshProUGUI firstLineText; // Reference to the first line Text UI element
    public TextMeshProUGUI secondLineText; // Reference to the second line Text UI element
    private List<string> congratulationQuotes; // List to store the congratulation quotes
    private List<string> motivationalQuotes; // List to store the motivational quotes

    void Start()
    {
        // Initialize the list of first line quotes
        congratulationQuotes = new List<string>
        {
            "Learning Legend!", "Knowledge Knight!", "Academic Ace!", "Scholar Superstar!", "Intellect Icon!",
            "Brainy Boss!", "Smart Sage!", "Wisdom Wizard!", "Genius Guru!", "Savvy Student!"
        };

        // Initialize the list of second line quotes
        motivationalQuotes = new List<string>
        {
            "Take a bow!", "Bravo!", "Kudos to you!", "Well done!", "Fantastic job!",
            "You did it!", "Amazing effort!", "Outstanding!", "Way to go!", "Keep it up!"
        };
        DisplayRandomQuotes();
    }

    void DisplayRandomQuotes()
    {
        // Select a random quote from the first line list
        int randomIndex1 = Random.Range(0, congratulationQuotes.Count);
        string randomCongratulationQuote = congratulationQuotes[randomIndex1];

        // Select a random quote from the second line list
        int randomIndex2 = Random.Range(0, motivationalQuotes.Count);
        string randomMotivationalQuote = motivationalQuotes[randomIndex2];

        // Display the selected quotes in the Text UI elements
        firstLineText.text = randomCongratulationQuote;
        secondLineText.text = randomMotivationalQuote;
    }

    // This method can be called when a lesson is completed
    public void OnLessonComplete()
    {
        DisplayRandomQuotes();
    }
}
```

Figure 4.60: Quotes Generator script

When users click the ‘Finish Lesson’ button on the final learning panel, the OnLessonComplete function in the Quotes Generator script is triggered. This function generates and displays random quotes on the ending panel, offering both congratulatory and motivational messages. The Quotes Generator script includes fields for firstLineText and secondLineText, which must be assigned to TextMeshProUGUI objects in the EndPanel (Figure 4.59). As shown in Figure 4.60, the script uses lists of quotes to randomly select the displayed messages.

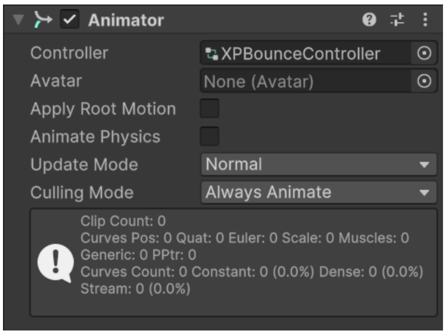


Figure 4.61: Animator component in the XPDisplayer object

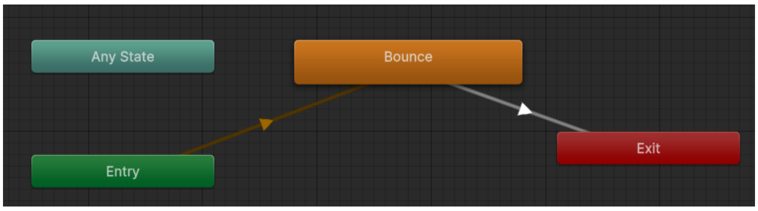


Figure 4.62: Animator panel of the XPBounceController's bounce effect

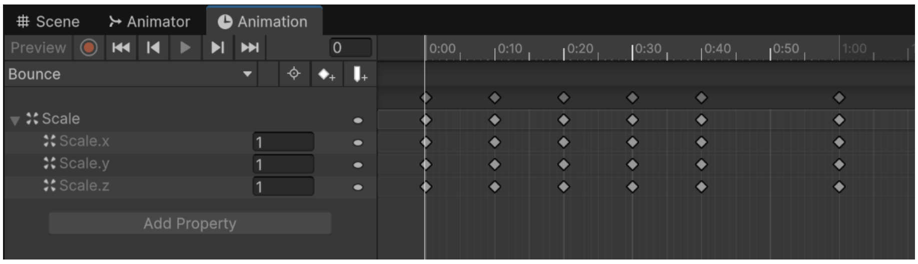


Figure 4.63: Animation panel of the XPBounceController's bounce effect

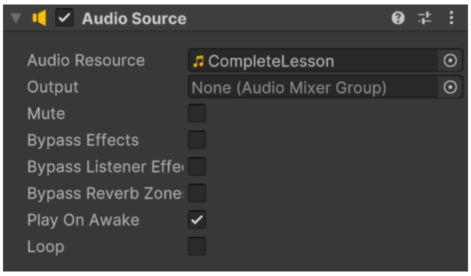


Figure 4.64: Complete lesson sound effect mp3 assigned to Audio Source object

The XPDisplayer object within the ending panel features a bounce effect, enhanced by a sound effect that plays when the panel appears. This effect adds a dynamic and engaging touch to the scene. The bounce animation is managed by an Animator component attached to the XPDisplayer (Figure 4.61). The animation adjusts the scale properties of the XPDisplayer as illustrated in Figure 4.63, creating a pulsating or bouncing effect, which helps to make the completion of the lesson more visually stimulating and rewarding.

4.2.4 Hands-on Experiment Module

The hands-on experiment module for both free fall motion and force topics of this application is demonstrated using XR Interaction Toolkit which creates a virtual reality (VR) environment, where users can move around, interact with objects using keyboard key and virtual controllers. A headset with controllers can be used in this scene too.

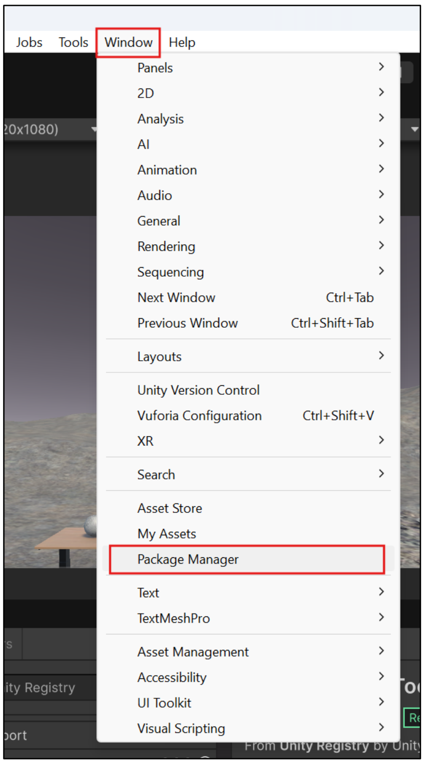


Figure 4.65: Window Panel in Unity

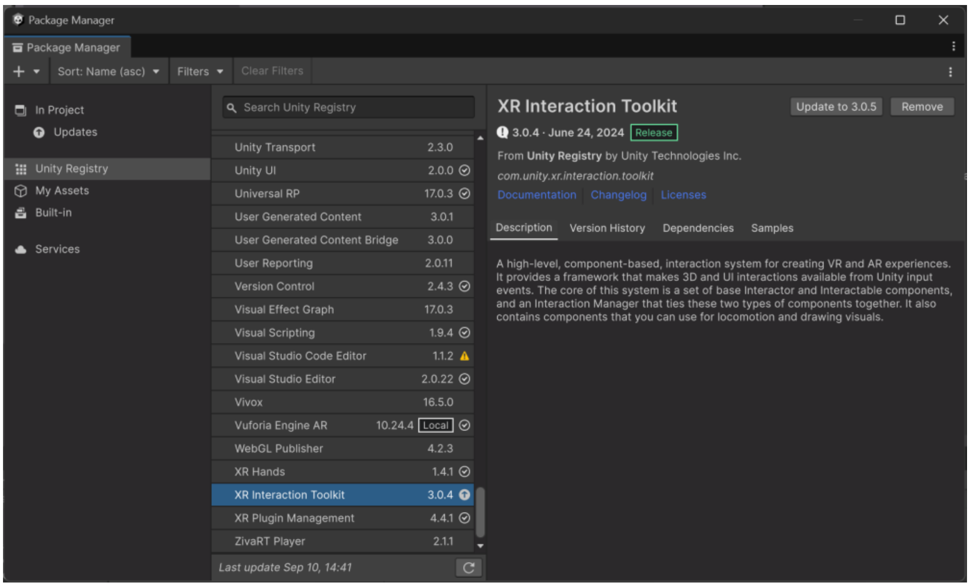


Figure 4.66: XR Interaction Toolkit package

To create the VR environment, XR Interaction Toolkit package needs to be installed via the Unity Package Manager as shown in 4.66. The Unity Package Manager window can be opened through Window ribbon in Unity as shown in Figure 4.65. Then, search for XR Interaction Toolkit in the Unity Registry and click install.

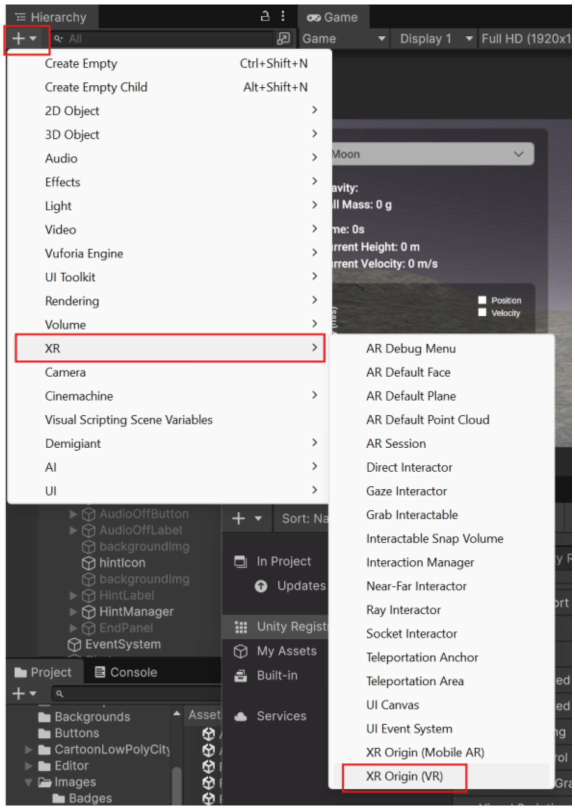


Figure 4.67: Instruction to add XR Orign (VR) to scene

The **XR Origin** represents the player's head and hand positions in the virtual world. It includes the camera and controller representations. It is added to the scene by clicking on the '+' Button, select XR, then select XR Origin.

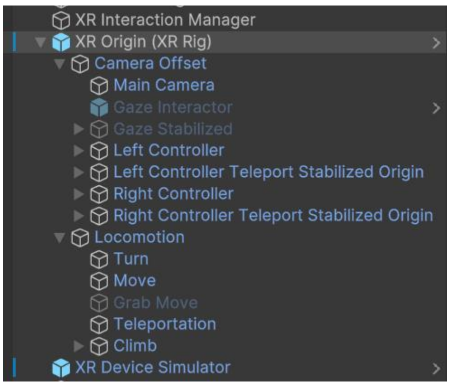


Figure 4.68: XR Origin's components

The **XR Origin** GameObject as shown in Figure 4.68 will then be added to the scene with the necessary components such as **Camera Offset** (manages the offset between the XR Origin and the camera), **Main Camera** (represents the player's viewpoint), **LeftHand Controller** and **RightHand Controller** (represent the player's controllers).

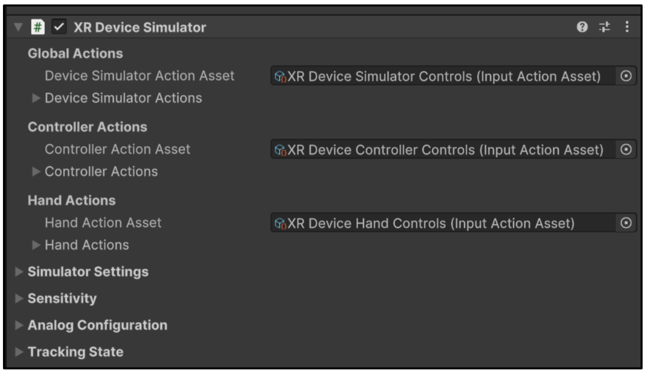


Figure 4.69: XR Device Simulator's Inspector

Figure 4.70: XR Device Simulation Instruction

The **XR Device Simulator** GameObject is also created which comes with the necessary components as shown in Figure 4.69 to simulate head and hand movements using keyboard and mouse inputs. Figure 4.70 shows the instruction to control the head and hand movements using keyboard and mouse inputs. For example, key ‘W’, ‘S’, ‘A’, and ‘D’ indicate the forward, backward, leftward, and rightward movements respectively, while key ‘Q’ and ‘E’ controls the upward and downward movements. To use the left controller, click key ‘T’, while ‘Y’ for right controller.

4.2.4.1 Free Fall Motion Topic's Hands-on Experiment Module

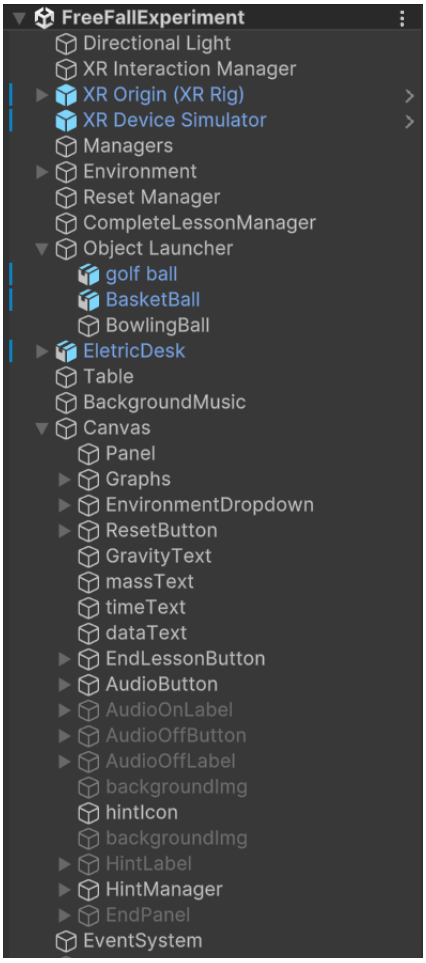


Figure 4.71: FreeFallExperiment's hierarchy

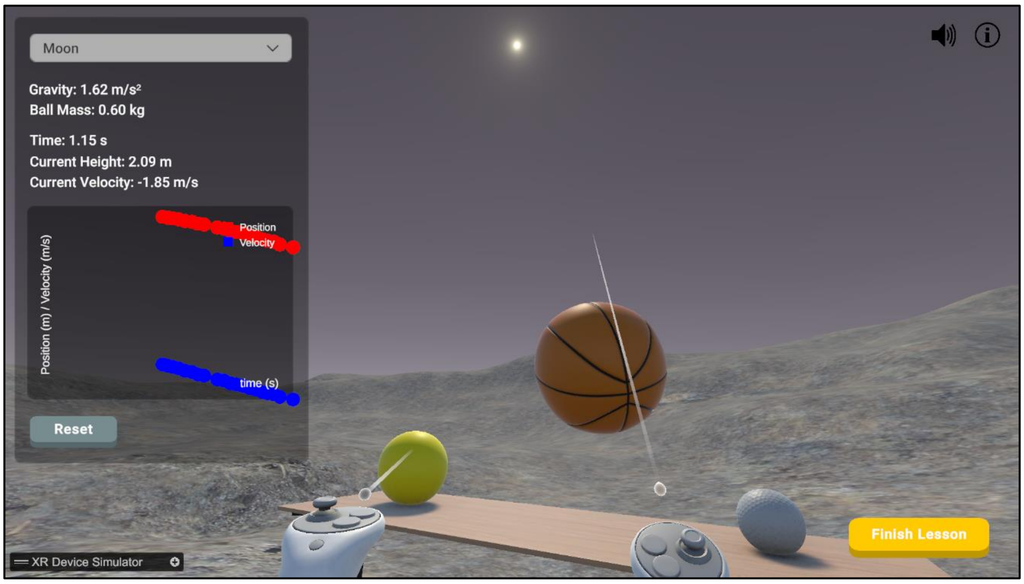


Figure 4.72: Free Fall Motion Experiment UI

The free fall experiment module as shown in Figure 4.72 was developed to allow users to explore the effects of gravity on different objects. Three balls, each with a different mass (golf ball, basketball, and bowling ball), are placed on a virtual table within a VR environment. To simulate the experiment, a dropdown menu was implemented to allow the user to select different gravitational environments: Earth, Moon, and Mars. Each environment has varying gravity values to influence the behaviour of the balls.

Using the XR controller, the user can grab any of the three balls and position them at different heights. Upon release, the ball falls according to the selected gravitational conditions. The experiment tracks and displays key information such as the height of the drop, the speed of the ball during the fall, and the time it takes for the ball to hit the ground. These results are represented as text or plotted on graphs for a visual understanding of how different masses and gravities affect the motion.

Figure 4.71 shows the hierarchy of the FreeFallExperiment scene, which consists of the Environment (the terrain of the environment), ResetManager (handles scene reset), CompleteLessonManager (handles complete lesson matter), Object Launcher (balls object), Table, BckgroundMusic, and Canvas.

```
using UnityEngine;

public enum Environment
{
    Earth,
    Mars,
    Moon
}

[System.Serializable]
public class EnvironmentColors
{
    public Color[] layerColors = new Color[4];
}
```

Figure 4.73: Environment Definition script

```
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.UI;
using TMPro;

public class EnvironmentManager : MonoBehaviour
{
    public TMP_Dropdown environmentDropdown;
    public List<GameObject> balls;
    public TextMeshProUGUI gravityText;
    public Terrain terrain;

    [SerializeField] private EnvironmentColors earthColors;
    [SerializeField] private EnvironmentColors marsColors;
    [SerializeField] private EnvironmentColors moonColors;

    private Dictionary<string, float> gravityDict = new Dictionary<string, float>
    {
        { "Mars", 3.71f },
        { "Moon", 1.62f },
        { "Earth", 9.81f }
    };

    void Start()
    {
        environmentDropdown.onValueChanged.AddListener(delegate { ChangeEnvironment(); });
        ChangeEnvironment(); // Set initial environment
    }

    public void ChangeEnvironment()
    {
        string selectedEnvironment = environmentDropdown.options[environmentDropdown.value].text;
        float selectedGravity = gravityDict[selectedEnvironment];

        // Update gravity
        Physics.gravity = new Vector3(0, -selectedGravity, 0);
        UpdateGravityText(selectedEnvironment, selectedGravity);


        switch (selectedEnvironment)
        {
            case "Mars":
                SetTerrainLayerColors(marsColors);
                break;
            case "Moon":
                SetTerrainLayerColors(moonColors);
                break;
            case "Earth":
                SetTerrainLayerColors(earthColors);
                break;
        }

        foreach (var ball in balls)
        {
            Rigidbody rb = ball.GetComponent<Rigidbody>();
            rb.linearVelocity = Vector3.zero; // Reset velocity
            rb.angularVelocity = Vector3.zero; // Reset angular velocity
            ball.transform.position = new Vector3(ball.transform.position.x, 10, ball.transform.position.z); // Reset position
        }
    }
```

Figure 4.74: Environment Manager script (Part A)

```
    private EnvironmentColors GetColorsForEnvironment(Environment env)
    {
        switch (env)
        {
            case Environment.Earth:
                return earthColors;
            case Environment.Mars:
                return marsColors;
            case Environment.Moon:
                return moonColors;
            default:
                return earthColors;
        }
    }

    private void SetTerrainLayerColors(EnvironmentColors colors)
    {
        TerrainLayer[] layers = terrain.terrainData.terrainLayers;

        for (int i = 0; i < layers.Length && i < colors.layerColors.Length; i++)
        {
            layers[i].diffuseRemapMin = Color.black;
            layers[i].diffuseRemapMax = colors.layerColors[i];
        }

        terrain.terrainData.terrainLayers = layers;
    }

    private void UpdateGravityText(string environment, float gravity)
    {
        gravityText.text = $"Gravity: {gravity} m/s²";
    }
}
```

Figure 4.75: Environment Manager script (Part B)

The free fall experiment module's development involved a combination of user interaction, gravity manipulation, and environmental changes. The script provided, EnvironmentManager (Figure 4.74 and 4.75), plays a critical role in managing the selection of different environments (Moon, Earth, and Mars) and updating the physics of the scene to reflect the correct gravitational values. Below shows the key components of the script:

1. Dropdown Selection for Environment:

Figure 4.76: EnvironmentDropdown GameObject

The `TMP_Dropdown environmentDropdown` lets users select their desired environment as shown in Figure 4.76. Options include Moon, Earth, and Mars, each with distinct gravitational forces. The onValueChanged event listener is set up to trigger the ChangeEnvironment() function whenever a different environment is selected.

2. **Gravity Settings**: A dictionary (`gravityDict`) stores the gravity values for each environment. For Moon, the gravity is set at 1.62 m/s^2, for Earth, it's 9.81 m/s^2, and for the Mars, it's 3.71 m/s^2. Upon environment selection, the script dynamically adjusts the `Physics.gravity` vector to reflect the chosen environment's gravitational force. This ensures that the behavior of the balls, in terms of free fall speed and acceleration, matches real-world expectations.
3. **Visual Feedback**: The `gravityText` element provides real-time updates to the user, displaying the current gravity in the format: "Gravity: X m/s^2" as shown in the UI (Figure 4.65). This helps users visually understand the current environmental conditions.
4. **Reset Ball Positions**: The balls (golf ball, basketball, and bowling ball) are represented as GameObjects stored in a `List<GameObject> balls`. When the environment changes, the balls are reset by:

- Setting the linear and angular velocity of each ball to zero, ensuring they stop moving before applying new gravitational values.
- Resetting their positions to a fixed height (e.g., 10 units above the ground), so the user can observe their free fall from the same height under different gravitational conditions.

5. **Terrain Color Change**:

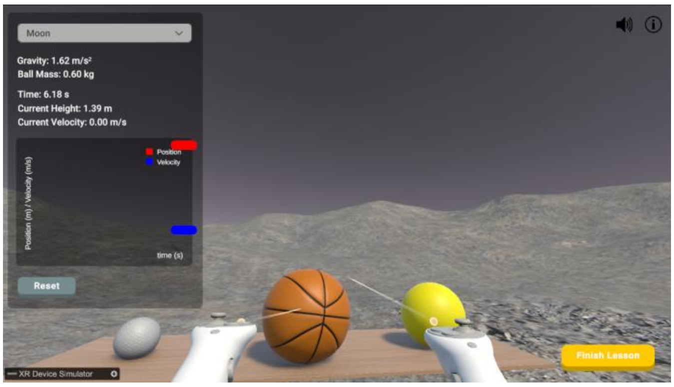


Figure 4.77: Moon Terrain Colour

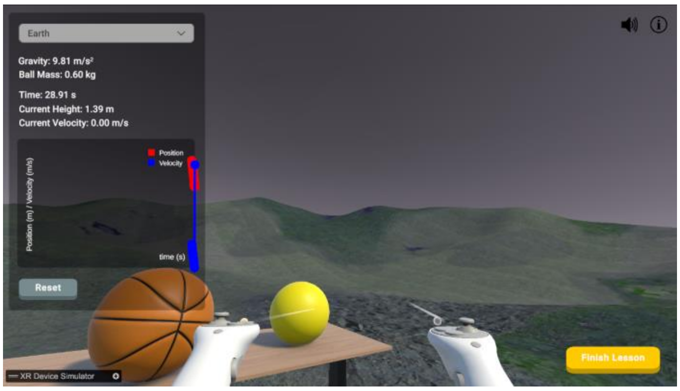


Figure 4.78: Earth Terrain Colour

Figure 4.79: Mars Terrain Colour

For a more immersive experience, the terrain visuals are updated to reflect the selected environment. This is achieved through the `SetTerrainLayerColors` function, which adjusts the terrain's texture colours. Each environment has predefined `EnvironmentColors` settings (for Moon, Earth, and Mars), giving users visual feedback that they are in a different environment. Figures 4.77, 4.78, and 4.79 show the terrain colours of different environments.

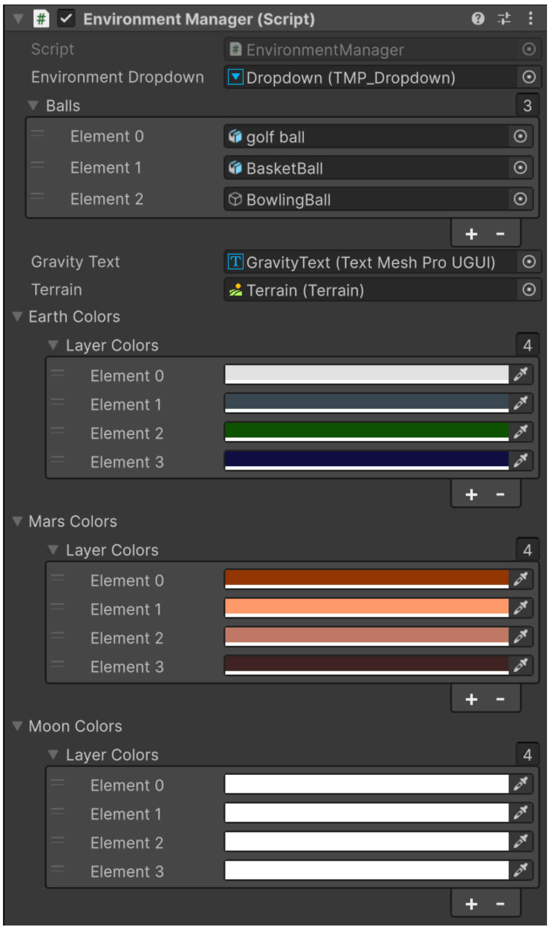


Figure 4.80: Environment Manager script attached to Environment GameObject

Figure 4.80 shows the Environment Manager's inspector panel, where several variables and references have been assigned to create the desired functionality for the free fall experiment. These include the Environment Dropdown, Balls (golf ball, basketball, and bowling ball), Gravity Text, and Terrain (a reference to the terrain object in the scene that will be visually updated with colors depending on the selected environment). Additionally, Earth, Mars, and Moon Colors are defined with four color elements each, representing an Earth-like terrain, the red, barren landscape of Mars, and the desolate, lunar surface of the Moon, respectively.

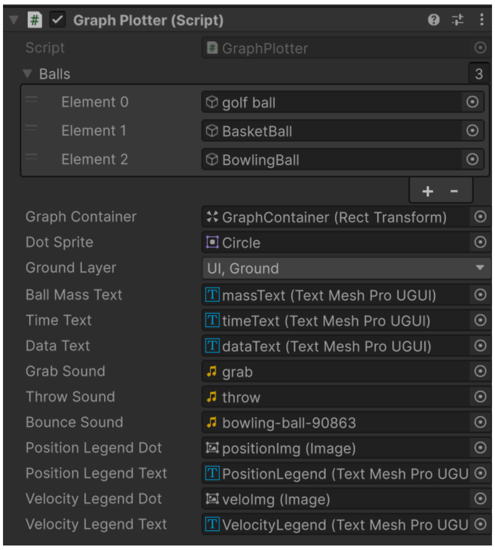


Figure 4.81: Graph Plotter script assigned to Object Launcher GameObject

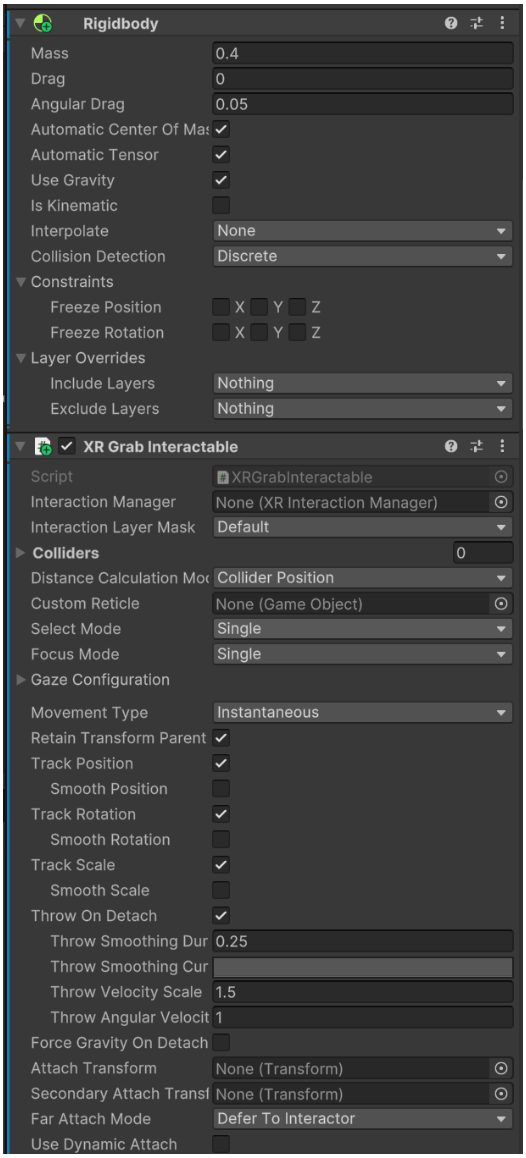


Figure 4.82: Ball's inspector panel

```
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.UI;
using TMPro;
using UnityEngine.XR.Interaction.Toolkit;

public class GraphPlotter : MonoBehaviour
{
    //public GameObject ball;
    public List<GameObject> balls;
    public RectTransform graphContainer;
    public Sprite dotSprite;
    public LayerMask groundLayer;

    public TextMeshProUGUI ballMassText;
    public TextMeshProUGUI timeText;
    public TextMeshProUGUI dataText;

    public AudioClip grabSound;
    public AudioClip throwSound;
    public AudioClip bounceSound;


    public Image positionLegendDot;
    public TextMeshProUGUI positionLegendText;
    public Image velocityLegendDot;
    public TextMeshProUGUI velocityLegendText;

    private List<float> timeData = new List<float>();
    private List<float> positionData = new List<float>();
    private List<float> velocityData = new List<float>();

    private float startTime;
    private Rigidbody rb;
    private GameObject activeBall;
    private bool isTracking = false;
    private bool ballReleased = false;

    private AudioSource audioSource;

    private float previousVelocityY;

    void Start()
    {
        foreach (var ball in balls)
        {
            UnityEngine.XR.Interaction.Toolkit.Interactables.XRGrabInteractable grabInteractable =
                ball.GetComponent<UnityEngine.XR.Interaction.Toolkit.Interactables.XRGrabInteractable>();
            grabInteractable.selectEntered.AddListener(OnBallGrabbed);
            grabInteractable.selectExited.AddListener(OnBallReleased);
            ball.AddComponent<AudioSource>();
        }

        // Set legend colors and labels
        positionLegendDot.color = Color.red;
        positionLegendText.text = "Position";
        velocityLegendDot.color = Color.blue;
        velocityLegendText.text = "Velocity";
    }
```

Figure 4.83: Graph Plotter script (Part A)

```
void Update()
{
    float height = activeBall.transform.position.y;
    Vector3 velocity = activeBall.GetComponent<Rigidbody>().linearVelocity;

    if (ballReleased && isTracking)
    {
        float currentTime = Time.time - startTime;
        timeText.text = $"Time: {currentTime:F2} s\n";

        timeData.Add(currentTime);
        positionData.Add(activeBall.transform.position.y); // Track Y position for simplicity
        velocityData.Add(rb.linearVelocity.y); // Track Y velocity for simplicity

        DetectBounce();
        DrawGraph();
    }

    dataText.text = $"Current Height: {height:F2} m\n" +
                    $"Current Velocity: {velocity.y:F2} m/s\n";
}

private void OnBallGrabbed(SelectEnterEventArgs args)
{
    ballReleased = false;
    activeBall = args.interactableObject.transform.gameObject;
    rb = activeBall.GetComponent<Rigidbody>();
    rb.isKinematic = true;
    ballMassText.text = "Ball Mass: " + rb.mass.ToString("F2") + " kg"; // Display ball mass
    PlaySound(grabSound);
}

private void OnBallReleased(SelectExitEventArgs args)
{
    if (activeBall != null)
    {
        ballReleased = true;
        StartTracking();
        rb.isKinematic = false;
        PlaySound(throwSound);
    }
}

public void StartTracking()
{
    isTracking = true;
    startTime = Time.time;
    timeData.Clear();
    positionData.Clear();
    velocityData.Clear();
    previousVelocityY = rb.linearVelocity.y;
}

public void StopTracking()
{
    isTracking = false;
}
```

Figure 4.84: Graph Plotter script (Part B)

```
private void DrawGraph()
{
    // Clear existing graph
    foreach (Transform child in graphContainer)
    {
        Destroy(child.gameObject);
    }

    float graphHeight = graphContainer.sizeDelta.y;
    float graphWidth = graphContainer.sizeDelta.x;

    float yMin = Mathf.Min(Mathf.Min(positionData.ToArray()), Mathf.Min(velocityData.ToArray()));
    float yMax = Mathf.Max(Mathf.Max(positionData.ToArray()), Mathf.Max(velocityData.ToArray()));
    float xMax = timeData.Count > 0 ? timeData[timeData.Count - 1] : 1;
    float xMin = timeData.Count > 0 ? timeData[0] : 0;

    int maxVisiblePoints = 20; // Number of points visible on the graph
    int startIndex = Mathf.Max(0, timeData.Count - maxVisiblePoints);

    for (int i = startIndex; i < timeData.Count; i++)
    {
        float xPosition = ((timeData[i] - xMin) / (xMax - xMin)) * graphWidth;
        float yPosition = ((positionData[i] - yMin) / (yMax - yMin)) * graphHeight;
        float yVelocity = ((velocityData[i] - yMin) / (yMax - yMin)) * graphHeight;

        CreateCircle(new Vector2(xPosition, yPosition), Color.red); // Position in red
        CreateCircle(new Vector2(xPosition, yVelocity), Color.blue); // Velocity in blue

        if (i > startIndex)
        {
            CreateLine(new Vector2(((timeData[i - 1] - xMin) / (xMax - xMin)) * graphWidth, ((positionData[i - 1] - yMin) / (yMax - yMin)) * graphHeight),
                       new Vector2(xPosition, yPosition), Color.red);
            CreateLine(new Vector2(((timeData[i - 1] - xMin) / (xMax - xMin)) * graphWidth, ((velocityData[i - 1] - yMin) / (yMax - yMin)) * graphHeight),
                       new Vector2(xPosition, yVelocity), Color.blue);
        }
    }
}
```

Figure 4.85: Graph Plotter script (Part C)

```
private void CreateCircle(Vector2 anchoredPosition, Color color)
{
    GameObject gameObject = new GameObject("circle", typeof(Image));
    gameObject.transform.SetParent(graphContainer, false);
    gameObject.GetComponent<Image>().sprite = dotSprite;
    gameObject.GetComponent<Image>().color = color;
    RectTransform rectTransform = gameObject.GetComponent<RectTransform>();
    rectTransform.anchoredPosition = anchoredPosition;
    rectTransform.sizeDelta = new Vector2(11, 11);
    rectTransform.anchorMin = new Vector2(0, 0);
    rectTransform.anchorMax = new Vector2(0, 0);
}

private void CreateLine(Vector2 dotPositionA, Vector2 dotPositionB, Color color)
{
    GameObject gameObject = new GameObject("line", typeof(Image));
    gameObject.transform.SetParent(graphContainer, false);
    gameObject.GetComponent<Image>().color = color;
    RectTransform rectTransform = gameObject.GetComponent<RectTransform>();
    Vector2 dir = (dotPositionB - dotPositionA).normalized;
    float distance = Vector2.Distance(dotPositionA, dotPositionB);
    rectTransform.sizeDelta = new Vector2(distance, 3f);
    rectTransform.anchorMin = new Vector2(0, 0);
    rectTransform.anchorMax = new Vector2(0, 0);
    rectTransform.anchoredPosition = dotPositionA + dir * distance * .5f;
    rectTransform.localEulerAngles = new Vector3(0, 0, GetAngleFromVectorFloat(dir));
}

private float GetAngleFromVectorFloat(Vector2 dir)
{
    float n = Mathf.Atan2(dir.y, dir.x) * Mathf.Rad2Deg;
    if (n < 0) n += 360;
    return n;
}

private void DetectBounce()
{
    if (previousVelocityY < 0 && rb.linearVelocity.y > 0)
    {
        PlaySound(bounceSound);
        StopTracking();
    }
    previousVelocityY = rb.linearVelocity.y;
}

private void PlaySound(AudioClip clip)
{
    audioSource = activeBall.GetComponent<AudioSource>();
    audioSource.PlayOneShot(clip);
}
}
```

Figure 4.86: Graph Plotter script (Part D)

The Object Launcher GameObject is composed of three child GameObjects (Figure 4.71), each representing a different ball. As shown in Figure 4.82, each ball is equipped with a Rigidbody component to handle physics interactions and an XR Grab Interactable component to enable grabbing functionality. the VR environment effectively.

The GraphPlotter script attached to the Object Laucher GameObject, handles the plotting of position and velocity graphs for balls in a free-fall experiment in Unity, as well as tracking and playing audio feedback during interactions with the balls. Here's a breakdown of its key components and functionality:

1. **Track Ball Interaction**:

- **Grabbing the Ball**: When a user grabs a ball, the script: (1) sets the grabbed ball as activeBall; (2) retrieves and displays the ball's mass; and (3) disables the ball's physics simulation (isKinematic = true) so it can be manually manipulated.

- **Releasing the Ball**: When the ball is released, the script: (1) sets ballReleased to true; (2) signaling that tracking should start; (3) enables physics simulation for the ball (isKinematic = false); (4) plays a sound indicating the ball has been thrown; and (5) begins tracking the ball's motion.

2. **Track and Display Data**:

- **Time Tracking**: Captures the elapsed time since the ball was released.
- **Position and Velocity Tracking**: Records the ball's vertical position and velocity at each time interval after release.
- **UI Updates**: Updates the display with the current height and velocity of the ball, as well as the time elapsed since release.

3. **Visualize Data on Graph**:

- **Draw Graph**: Continuously updates a graph to visualize: (1) position – plotted as red dots and lines to show changes in height over time; (2) velocity – plotted as blue dots and lines to show changes in vertical velocity over time.
- **Graph Construction**: (1) clears previous graph elements; (2) calculates the position of new data points on the graph; and (3) draws lines connecting these points to show trends in position and velocity.

4. **Detect and Handle Bounces**:

- **Bounce Detection**: Monitors the vertical velocity of the ball to detect when it bounces (velocity changes from negative to positive).
- **Bounce Response**: Plays a bounce sound and stops tracking if a bounce is detected.

5. **Manage Sounds**:

- **Play Sounds**: Plays specific sounds for different events (grabbing, throwing, bouncing) to enhance the user experience.

Figure 4.81 shows the assignments of the Graph Plotter script, which include the Balls, Graph Container, Dot Sprite, Ground Layer, Ball Mass Text, Time Text, Data Text, Grab Sound, Throw Sound, Bounce Sound, Position Legend Dot, Position Legend Text, Velocity Legend Dot, and Velocity Legend Text.

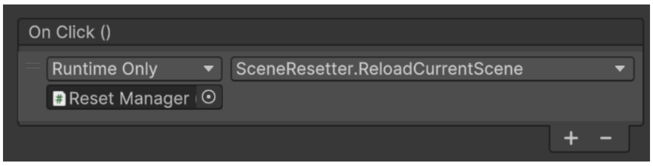


Figure 4.87: onClick function of ResetButton

```
using UnityEngine;
using UnityEngine.SceneManagement;

public class SceneResetter : MonoBehaviour
{
    // This method reloads the current scene
    public void ReloadCurrentScene()
    {
        SceneManager.LoadScene(SceneManager.GetActiveScene().name);
    }
}
```

Figure 4.88: SceneResetter script

The reset button allows user to reset the scene, whether if they want the balls to back to its original position or they would like the default scene. Upon clicking it, the ReloadCurrentScene function in the SceneResetter script (Figure 4.88) is called via the onClick function as shown in Figure 4.87 to reload the current scene.

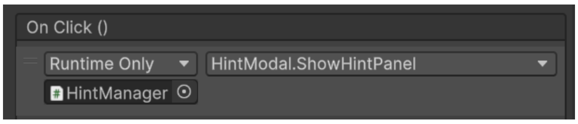


Figure 4.89: onClick function of hintIcon

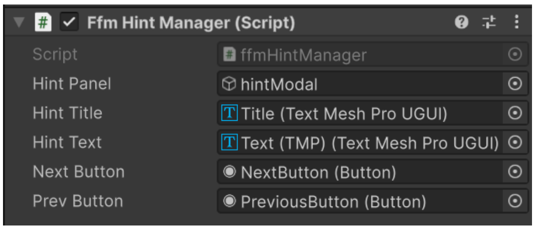


Figure 4.90: ffm Hint Manager script attached to HintManager GameObject

```
using UnityEngine;
using UnityEngine.UI;
using TMPro;

public class ffmHintManager : MonoBehaviour
{
    public GameObject hintPanel; // Panel that shows the hints
    public TextMeshProUGUI hintTitle; // Text component for the hint title
    public TextMeshProUGUI hintText; // Text component to display the hint
    public Button nextButton; // Button to go to the next hint
    public Button prevButton; // Button to go to the previous hint

    private int currentHintIndex = 0;

    private string[] hintTitles = new string[]
    {
        "Choose Your Ball",
        "Pick an Environment",
        "Observe the Motion",
        "Analyse the Results"
    };

    // Array of hints
    private string[] hints = new string[]
    {
        "To start the experiment, grab a ball of your chosen mass and lift it to your desired height.",
        "Select different environments with varying gravity to see how they impact the motion.",
        "Throw the ball and observe the velocity and the time it takes for the ball to reach the ground.",
        "Analyze how different masses and gravity conditions affect the results."
    };

    void Start()
    {
        // Initialize the first hint
        UpdateHint();

        // Add listeners to buttons
        nextButton.onClick.AddListener(NextHint);
        prevButton.onClick.AddListener(PreviousHint);

        // Initially disable the prevButton if we are on the first hint
        prevButton.interactable = currentHintIndex > 0;
    }
```

Figure 4.91: ffm Hint Manager script (Part A)

```
    // Updates the hint text based on the currentHintIndex
    void UpdateHint()
    {
        hintTitle.text = hintTitles[currentHintIndex];
        hintText.text = hints[currentHintIndex];
        nextButton.interactable = currentHintIndex < hints.Length - 1;
        prevButton.interactable = currentHintIndex > 0;
    }

    // Go to the next hint
    void NextHint()
    {
        if (currentHintIndex < hints.Length - 1)
        {
            currentHintIndex++;
            UpdateHint();
        }
    }

    // Go to the previous hint
    void PreviousHint()
    {
        if (currentHintIndex > 0)
        {
            currentHintIndex--;
            UpdateHint();
        }
    }

    // Function to show the hint panel
    public void ShowHintPanel()
    {
        hintPanel.SetActive(true);
    }

    // Function to hide the hint panel
    public void HideHintPanel()
    {
        hintPanel.SetActive(false);
    }
}
```

Figure 4.92: ffm Hint Manager script (Part B)

Figure 4.93: Hint Modal UI

The hintIcon GameObject, located in the top right corner of the scene, activates the Hint Modal (Figure 4.93) when clicked. This modal provides users with instructions related to the module. Figure 4.89 illustrates the onClick function of the hintIcon, which triggers the display of the modal. The Hint Modal comprises several pages, requiring both navigation buttons and conditional logic to enable or disable buttons based on the current page.

The script, ffmHintManager (referenced in Figures 4.91 and 4.92), plays a crucial role in managing and displaying a series of hints designed to guide users step-by-step through an experiment, likely tied to the free fall experiment module. Below is an overview of the script's key functions:

1. **Hint Navigation**: Users can navigate between different hints using the NextHint() and PreviousHint() functions, which update the displayed hint and its title based on the current index.
2. **Conditional Button Interaction**: The next and previous buttons are disabled or enabled based on whether the user is on the first or last hint.
3. **Hint Panel Control**: The ShowHintPanel() and HideHintPanel() methods allow external scripts or UI interactions to control whether the hint panel is visible or hidden, providing flexibility for integrating the hint system into a larger application.

Upon clicking the ‘Finish Lesson’ button, an ending panel will be shown too, similar to the tutorial module’s ending panel.

4.2.4.2 Force Topic's Hands-on Experiment Module

The Force Experiment Module shares several structural elements with the Free Fall Motion Experiment Module, such as common interface features like the audio button, finish lesson button, reset button, hint button, and end panel. These functions work similarly to those outlined in the free fall module and offer consistent user interaction and navigation.

However, this section will focus on the main function of the force experiment, which demonstrates how force, mass, and acceleration interact in a practical setting. The core of this module is centered on an interactive simulation where the user can apply varying amounts of force to a trolley, adjust the mass by adding or removing objects, and observe the resulting changes in motion.

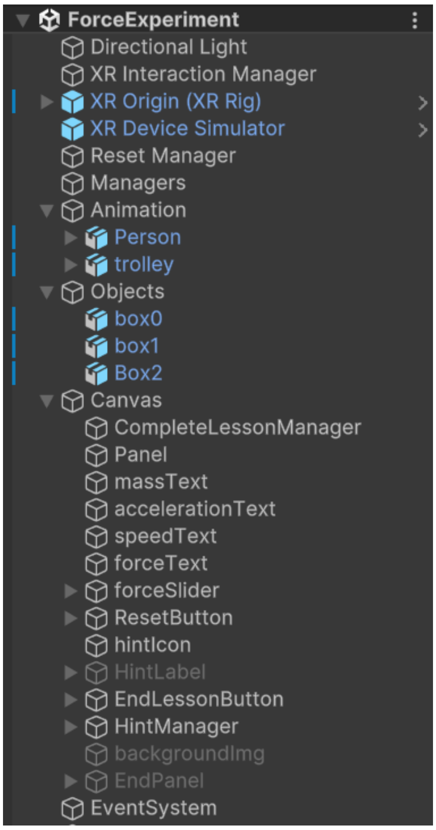


Figure 4.94: ForceExperiment's hierarchy

Figure 4.95: ForceExperiment UI

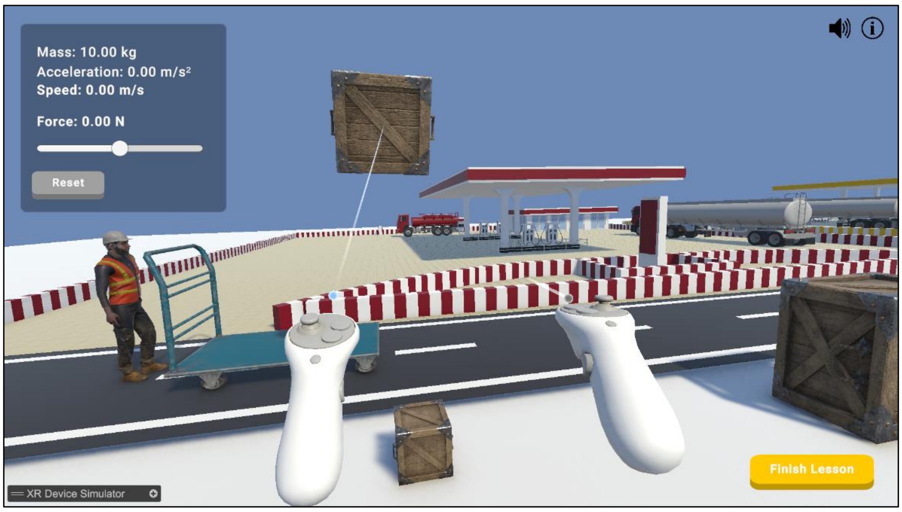


Figure 4.96: Demonstration of grab action

Figure 4.94 and 4.95 illustrates the hierarchy and user interface (UI) of ForceExperiment scene. Key features include:

- **Force Adjustment**: The user can apply different levels of force to the trolley using slider, the resulting acceleration and speed are dynamically calculated.
- **Mass Manipulation**: The user can add or remove objects to/from the trolley using the XR controller as shown in Figure 4.96, which changes the total mass, influencing the acceleration and speed in real-time.
- **Real-Time Feedback**: Key parameters such as force, mass, acceleration, and speed are displayed to the user, offering instant feedback on the effects of their interactions.
- **Character Animation**: A character is animated to push the trolley, synchronizing the animation with the applied force and resulting motion.

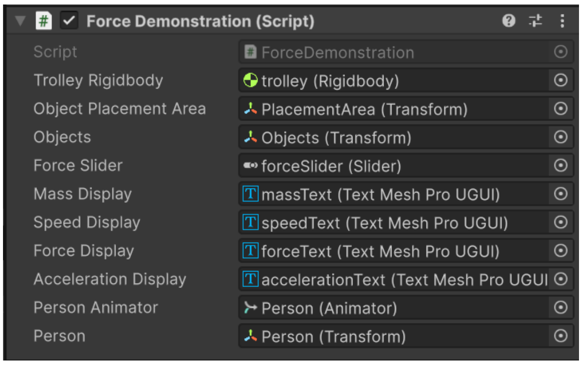


Figure 4.97: Assignments of Force Demonstration script

```
using UnityEngine;
using UnityEngine.UI;
using TMPro;

public class ForceDemonstration : MonoBehaviour
{
    public Rigidbody trolleyRigidbody;
    public Transform objectPlacementArea;
    public Transform objects;
    public Slider forceSlider;
    public TextMeshProUGUI massDisplay;
    public TextMeshProUGUI speedDisplay;
    public TextMeshProUGUI forceDisplay;
    public TextMeshProUGUI accelerationDisplay;
    public Animator personAnimator;
    public Transform person;

    private float totalMass = 10f; // Base mass of the trolley
    private float appliedForce = 0f;
    private float currentSpeed = 0f;
    private float acceleration = 0f;

    private static readonly int PushSpeedParameter = Animator.StringToHash("PushSpeed");
    private static readonly int DirectionParameter = Animator.StringToHash("Direction");

    private void Update()
    {
        UpdateForce();
        CalculateSpeed();
        UpdateDisplays();
        MoveTrolley();
        UpdatePersonAnimation();

        // Ensure the placement area remains aligned with the trolley
        objectPlacementArea.localPosition = Vector3.zero;
        objectPlacementArea.localRotation = Quaternion.identity;
    }

    private void UpdateForce()
    {
        appliedForce = forceSlider.value;
    }

    private void CalculateSpeed()
    {
        acceleration = appliedForce / totalMass;
        currentSpeed += acceleration * Time.deltaTime;
        // Apply some drag to prevent infinite acceleration
        currentSpeed *= 0.99f;
    }

    private void UpdateDisplays()
    {
        massDisplay.text = $"Mass: {totalMass:F2} kg";
        speedDisplay.text = $"Speed: {currentSpeed:F2} m/s";
        forceDisplay.text = $"Force: {appliedForce:F2} N";
        accelerationDisplay.text = $"Acceleration: {acceleration:F2} m/s²";
    }
```

Figure 4.98: Force Demonstration script (Part A)

```csharp
private void MoveTrolley()
{
    Vector3 movement = -trolleyRigidbody.transform.forward * (currentSpeed * Time.deltaTime);
    trolleyRigidbody.MovePosition(trolleyRigidbody.position + movement);

    // Move all objects parented to the trolley
    foreach (Transform child in trolleyRigidbody.transform)
    {
        child.Translate(movement, Space.Self);
    }
}

private void UpdatePersonAnimation()
{
    float absoluteSpeed = Mathf.Abs(currentSpeed);
    float normalizedSpeed = Mathf.Clamp01(absoluteSpeed / 5f); // Assuming 5 m/s is max speed

    float pushForceThreshold = 0.5f; // Adjust this value as needed
    personAnimator.SetFloat(PushSpeedParameter, normalizedSpeed);
    personAnimator.SetFloat(PushSpeedParameter, appliedForce > pushForceThreshold ? 1f : 0f);

    Vector3 personPosition = trolleyRigidbody.transform.position;
    personPosition += trolleyRigidbody.transform.forward * 1.68f;
    personPosition.y = person.position.y; // Keep the person's y-position the same
    person.position = personPosition;

    personAnimator.speed = Mathf.Lerp(personAnimator.speed, normalizedSpeed * 4f, Time.deltaTime * 2f);
}
```

Figure 4.99: Force Demonstration script (Part B)

```csharp
    public void AddObjectToTrolley(UnityEngine.XR.Interaction.Toolkit.Interactables.XRGrabInteractable grabbedObject)
    {
        Rigidbody objectRb = grabbedObject.GetComponent<Rigidbody>();
        if (objectRb != null)
        {
            totalMass += objectRb.mass;
            grabbedObject.transform.SetParent(objectPlacementArea, true);

            // Calculate the stack height
            float stackHeight = 0f;
            foreach (Transform child in objectPlacementArea)
            {
                if (child != grabbedObject.transform)
                {
                    stackHeight += child.GetComponent<Collider>().bounds.size.y;
                }
            }

            // Adjust the position of the new box based on the current stack height
            Vector3 newPosition = Vector3.zero;
            newPosition.y += stackHeight + (grabbedObject.GetComponent<Collider>().bounds.size.y / 2);
            grabbedObject.transform.localPosition = newPosition;

            // Preserve the original rotation
            grabbedObject.transform.localRotation = Quaternion.identity;

            objectRb.isKinematic = true;
        }
    }

    public void RemoveObjectFromTrolley(UnityEngine.XR.Interaction.Toolkit.Interactables.XRGrabInteractable removedObject)
    {
        Rigidbody objectRb = removedObject.GetComponent<Rigidbody>();
        if (objectRb != null)
        {
            totalMass -= objectRb.mass;
            removedObject.transform.SetParent(objects, true);

            objectRb.isKinematic = false;

            removedObject.transform.localPosition = Vector3.zero;
        }
    }
}
```

Figure 4.100: Force Demonstration script (Part C)

The script, ForceDemonstration (Figure 4.98, 4.99, and 4.100) that is attached to the Managers GameObject, is to simulate the physical behavior of a trolley based on the force applied, its mass, and its resulting acceleration and speed. It is part of a VR experience where users can manipulate the trolley by adjusting the applied force, adding/removing objects (which change the mass), and observing the resulting motion in real-time. Here are the key functions and components of the script:

1. **Force and Motion Calculation**:

   The script continuously calculates the acceleration and speed of the trolley based on Newton's second law (F = ma). It uses a slider (representing force) and adjusts the acceleration, speed, and motion of the trolley accordingly:

   - `UpdateForce()`: Reads the current value from the force slider.
   - `CalculateSpeed()`: Uses the formula $a = F/m$ to calculate acceleration and adjusts speed accordingly, factoring in drag to prevent infinite acceleration.

2. **Object Interaction**:

   - `AddObjectToTrolley()`: Allows users to add objects to the trolley. Each object's mass is added to the total mass of the trolley, impacting its acceleration and speed.
   - `RemoveObjectFromTrolley()`: Allows users to remove objects, subtracting the mass from the total trolley mass.

3. **Real-time UI Display**:

   The script updates the displayed mass, speed, force, and acceleration values on the screen using TextMeshProUGUI components to give real-time feedback to the user: massDisplay, speedDisplay, forceDisplay, and accelerationDisplay are updated based on the calculated values.

4. **Trolley Movement**:

   `MoveTrolley()`: Moves the trolley based on the current speed and applies the movement to all objects parented to the trolley. This ensures any object placed on the trolley also moves with it.

5. **Person Animation**:

   `UpdatePersonAnimation()`: Animates a character pushing the trolley based on the trolley's speed. It adjusts the animation speed and position of the character relative to the trolley, ensuring the animation is synchronized with the trolley's motion.

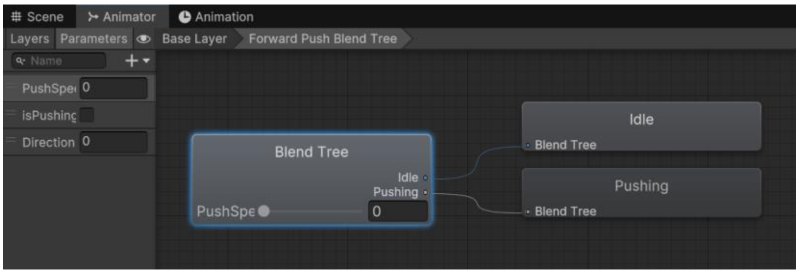


Figure 4.101: Blend Tree of the Person Animator

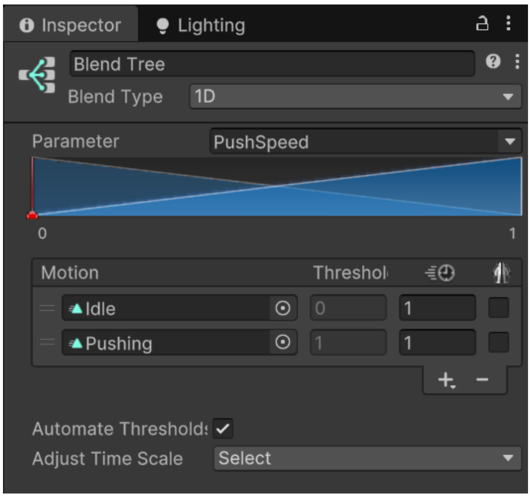


Figure 4.102: Blend Tree's inspector panel

The Person Animator component in the script is tied to the animation of the person pushing the trolley in the force demonstration. Specifically, the animator uses a Blend Tree as shown in Figure 4.101 to smoothly transition between different animations based on the input values such as speed and force applied. A **Blend Tree** allows for blending multiple animations together, ensuring that transitions between different actions (such as idle, walking, pushing, and stopping) happen smoothly. In this context:

- **PushSpeed Parameter**: This parameter adjusts how fast the person pushes the trolley based on the trolley's speed. As the trolley's speed increases (which is derived from the applied force), the blend tree adjusts the animation to show the person moving faster or slower.

The **Blend Tree** helps create a fluid motion where the person pushing the trolley accelerates or decelerates naturally, rather than using discrete animation steps. This ensures that the person's movement feels more realistic as it adapts to the dynamic changes in the scene.

6. **UI Interaction**:

   The script includes sliders and buttons in the UI that control the force applied to the trolley and update the display with the current force and mass dynamically.

7. **Object Placement Area**:

   The script ensures the *objectPlacementArea* remains aligned with the trolley, so objects added to the trolley are correctly positioned and move as part of the trolley's system.

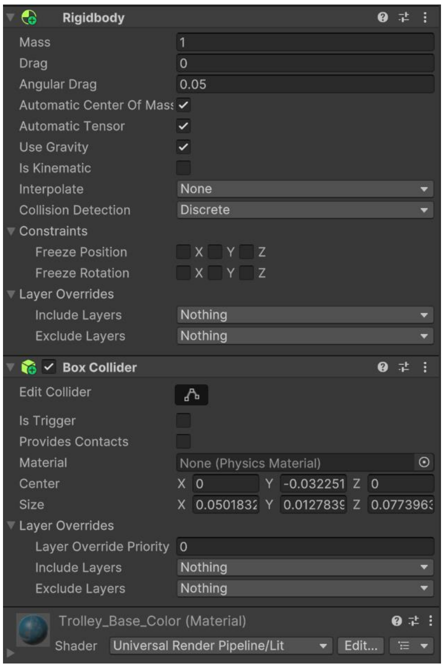


Figure 4.103: trolley's inspector panel

Figure 4.103 shows the trolley's inspector with the Rigidbody and Box Collider components. The Rigidbody controls the trolley's movement by applying physics-based forces and ensures it interacts properly with the physics system in Unity, while the Box Collider defines the physical boundaries of the trolley, enabling collision detection and ensuring that the trolley interacts with other objects in the environment realistically.

4.2.5 Interactive Assessment Module

This session will focus on the development of the interactive assessment module, which is designed with a structure that is consistent across both the Force and Free Fall Motion topics.

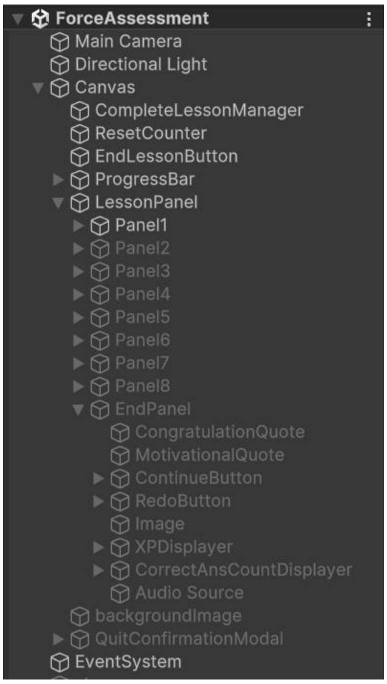


Figure 4.104: Assessment Module's hierarchy

Figure 4.104 shows the hierarchy of the assessment scene. While the interactive assessment module shares several similarities with the tutorial module, such as the use of an End Lesson button, a progress bar, and a CompleteLessonManager script, it incorporates specific features tailored to the assessment process.

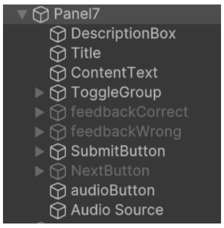


Figure 4.105: Child of Question Panel

Each question panel (as shown in Figure 4.105) is equipped with a DescriptionBox, Title, ContentText, Toggle Group (multiple choices radio button), feedback messages (for correct and wrong answer), SubmitButton, NetButton, audioButton, and Audio Source (narration of the question).

The toggle Group is managed by the MCQController script, which calculates the total number of correct answers given by the user.

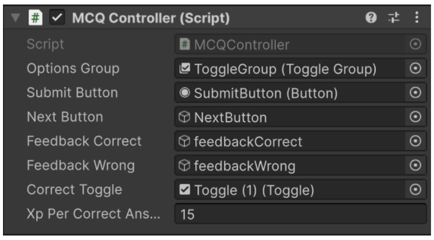


Figure 4.106: Assignments of MCQController script

```
using UnityEngine;
using UnityEngine.UI;
using TMPro;
using UnityEngine.SceneManagement;

public class MCQController : MonoBehaviour
{
    public ToggleGroup optionsGroup;       // Toggle group for answer options
    public Button submitButton;            // Button to submit the answer
    public GameObject nextButton;          // Button to go to the next question
    public GameObject feedbackCorrect;     // Panel shown when the answer is correct
    public GameObject feedbackWrong;       // Panel shown when the answer is incorrect
    public Toggle correctToggle;           // The correct answer toggle
    public int xpPerCorrectAnswer = 15;    // XP points awarded per correct answer

    private string correctAnswersKey;

    void Start()
    {
        // Determine the correct PlayerPrefs key based on the active scene
        string sceneName = SceneManager.GetActiveScene().name;
        if (sceneName == "FreeFallAssessment")
        {
            correctAnswersKey = "CorrectAnswers_FreeFall";
        }
        else if (sceneName == "ForceAssessment")
        {
            correctAnswersKey = "CorrectAnswers_Force";
        }

        submitButton.onClick.AddListener(CheckAnswer);  // Add listener to submit button
        submitButton.interactable = false;              // Disable submit button initially

        // Add listener to each toggle in the toggle group
        foreach (var toggle in optionsGroup.GetComponentsInChildren<Toggle>())
        {
            toggle.onValueChanged.AddListener(delegate {
                OnToggleValueChanged(toggle);
            });
        }
    }

    // Method called when any toggle is selected
    void OnToggleValueChanged(Toggle changedToggle)
    {
        submitButton.interactable = optionsGroup.AnyTogglesOn();  // Enable submit button when any option is selected
    }
```

Figure 4.107: MCQController script (Part A)

```
    // Method to check if the selected answer is correct
    void CheckAnswer()
    {
        Toggle selectedToggle = optionsGroup.GetFirstActiveToggle();  // Get the selected toggle

        if (selectedToggle != null)
        {
            if (selectedToggle == correctToggle)
            {
                feedbackCorrect.SetActive(true);   // Show correct feedback panel
                int currentXP = PlayerPrefs.GetInt("moduleXP", 0);
                currentXP += xpPerCorrectAnswer;
                PlayerPrefs.SetInt("moduleXP", currentXP);
                PlayerPrefs.Save();

                // Update and save the correct answer count
                int correctAnswers = PlayerPrefs.GetInt(correctAnswersKey, 0);
                correctAnswers++;
                PlayerPrefs.SetInt(correctAnswersKey, correctAnswers);
                PlayerPrefs.Save();
            }
            else
            {
                feedbackWrong.SetActive(true);   // Show incorrect feedback panel
            }
        }
        submitButton.gameObject.SetActive(false);  // Hide the submit button after submitting
        nextButton.SetActive(true);  // Show the next button after checking the answer
    }
}
```

Figure 4.108: MCQController script (Part B)

This script, MCQController (Figure 4.107 and 4.108), is responsible for handling the functionality of multiple-choice questions (MCQs) in an interactive assessment module in Unity. It manages user input, checks the correctness of the answers, provides feedback, and updates the user's XP and progress. Here's a breakdown of the key features of the script:

1. **PlayerPrefs Integration**: This script uses PlayerPrefs to store the user's current XP and the number of correct answers for each topic (Free Fall or Force). PlayerPrefs is a simple way to store data persistently between game sessions.
2. **Answer Submission and Validation**: The script allows users to select an answer from a group of toggles (radio buttons) and submit their choice. Upon submission, it checks if the selected answer is correct by comparing it to a predefined correct answer.
3. **Interactive Feedback**:

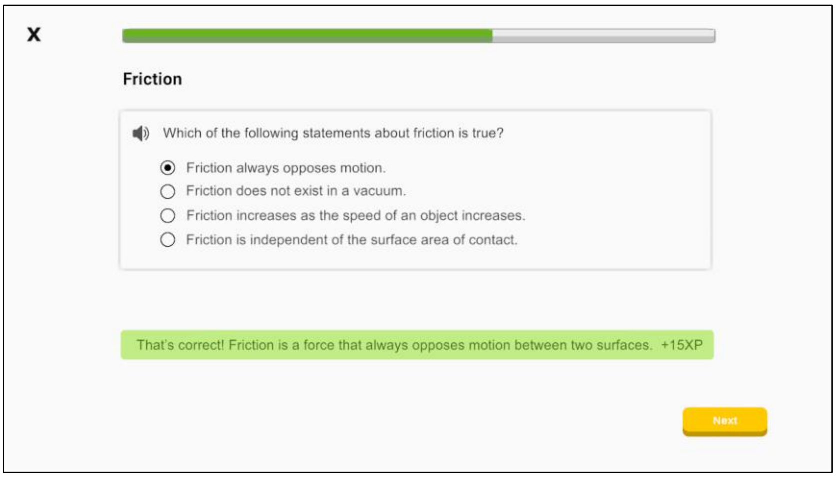


Figure 4.109: Correct answer feedback message

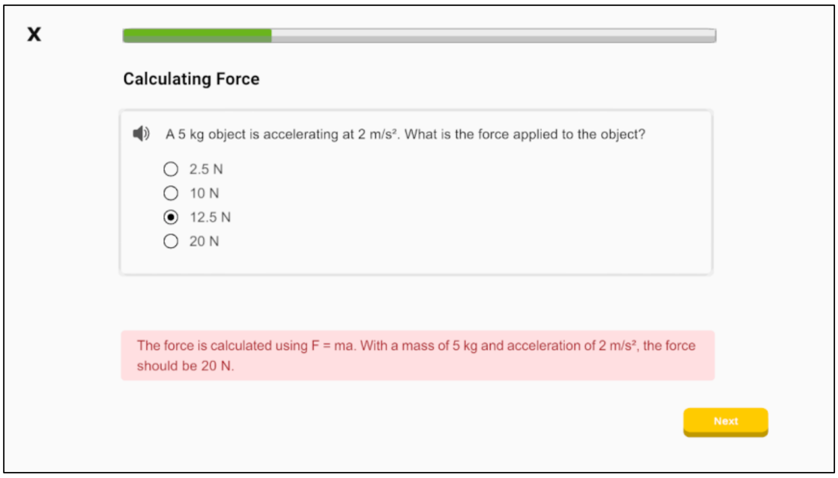


Figure 4.110: Incorrect answer feedback message

After the user submits an answer, they receive immediate feedback in the form of a panel that indicates whether their answer was correct or incorrect (as displayed in Figure 4.109 and 4.110). This feedback is crucial for improving the learning experience.

4. **XP Reward System**: The script awards experience points (XP) for each correct answer. It updates the user's total XP and saves this data using PlayerPrefs for later retrieval (like unlocking achievements).
5. **Progress Tracking**: It tracks the number of correct answers during the assessment and saves the count using PlayerPrefs, allowing the system to monitor user progress.
6. **Toggle and Button Controls**: The submit button is only enabled when the user selects an option, ensuring proper interaction flow. After submitting, the user can no longer interact with the options for that question.

Unlike the tutorial module, which includes both back and next navigation buttons for each panel, the assessment module intentionally omits the back button. This design choice reflects the nature of assessments, where users are not allowed to revisit previous questions, ensuring the integrity of their responses as they progress through the quiz.

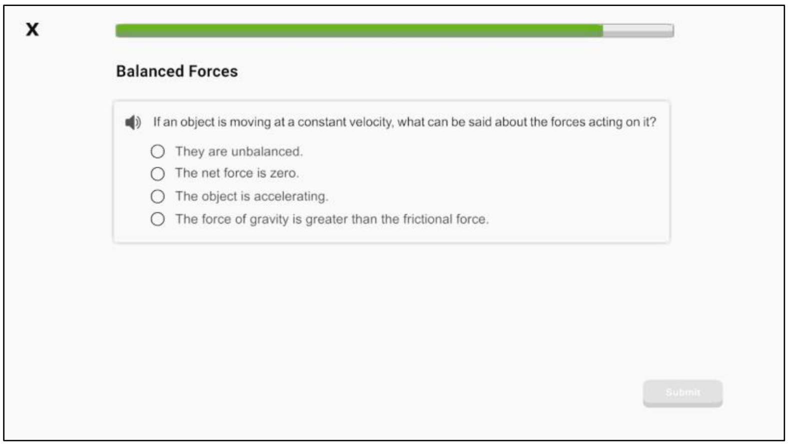


Figure 4.111: Question Panel with disabled 'Submit ' button

Each question includes a submit button that is initially disabled (Figure 4.111) but becomes active once the user selects any answer option. This 'submit' button allows users to check their responses against the correct answers. Based on the accuracy of their responses, immediate feedback is displayed, offering either positive reinforcement for correct answers or guidance for incorrect ones.

After submission, the submit button transforms into a next button, enabling users to seamlessly proceed to the following question.

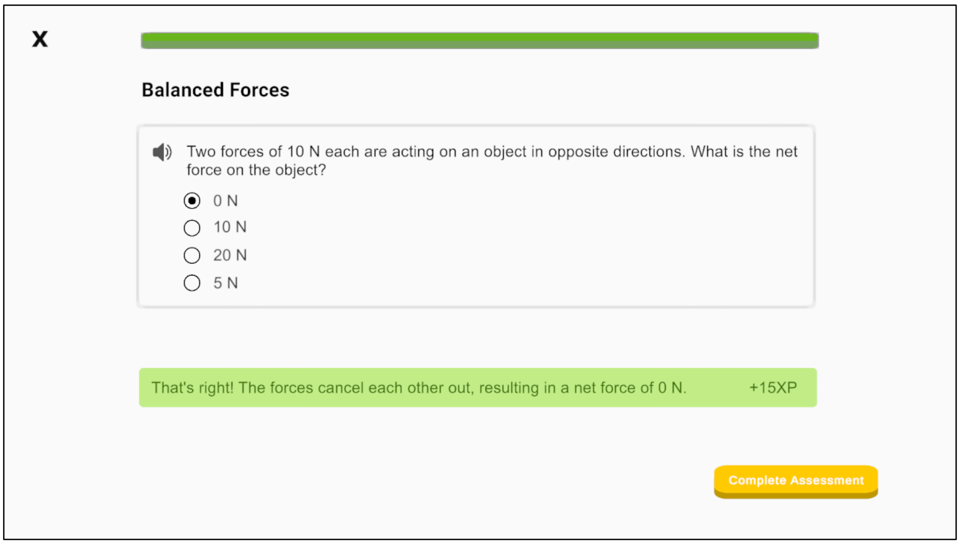


Figure 4.112: Last question's panel with Complete Assessment button

```csharp
using UnityEngine;
using TMPro;
using UnityEngine.SceneManagement;

public class ResetPlayerPrefs : MonoBehaviour
{
    public TextMeshProUGUI correctAnswersText;
    public TextMeshProUGUI xpText;
    public int totalQuestions;

    private string correctAnswersKey;

    void Start()
    {
        string sceneName = SceneManager.GetActiveScene().name;
        if (sceneName == "FreeFallAssessment")
        {
            correctAnswersKey = "CorrectAnswers_FreeFall";
        }
        else if (sceneName == "ForceAssessment")
        {
            correctAnswersKey = "CorrectAnswers_Force";
        }

        PlayerPrefs.SetInt(correctAnswersKey, 0);
        PlayerPrefs.SetInt("moduleXP", 0);
        PlayerPrefs.Save();
    }

    public void DisplayText()
    {
        // Get the number of correct answers
        int correctAnswers = PlayerPrefs.GetInt(correctAnswersKey, 0);
        int xp = PlayerPrefs.GetInt("moduleXP", 0);
        int totalXP = PlayerPrefs.GetInt("TotalXP", 0);
        totalXP += xp;
        PlayerPrefs.SetInt("TotalXP", totalXP);
        PlayerPrefs.Save();

        // Display the result
        xpText.text = xp + "";
        correctAnswersText.text = correctAnswers + " / " + totalQuestions;
    }
}
```

Figure 4.113: ResetPlayerPrefs script

Figure 4.114: 'Complete Assessment' button's Event Trigger component

As the user reaches the final question panel, the submit button is replaced with a "Complete Assessment" button as shown in Figure 4.112. This button triggers the DisplayText method in the ResetPlayerPrefs script (Figure 4.113) through the Event Trigger component's Pointer Down function (Figure 4.114), to display the number of correct answers at the ending panel.

The ResetPlayerPrefs script manages the resetting of player progress at the start of an assessment and displays the final results, including correct answers and XP, at the end.

The script resets the player's current progress by setting the correct answer count and XP (`moduleXP`) to zero to ensures that every assessment starts fresh. When the `DisplayText()` method is called, it retrieves the total correct answers and the XP the player earned during the assessment. It also updates the total XP by adding the XP earned from the current session to the previously accumulated total (`TotalXP`). The final results are then displayed on the screen by updating the text fields, `correctAnswersText` and `xpText` (child of EndPanel), which show the number of correct answers out of the total questions and the XP earned during the session, respectively.

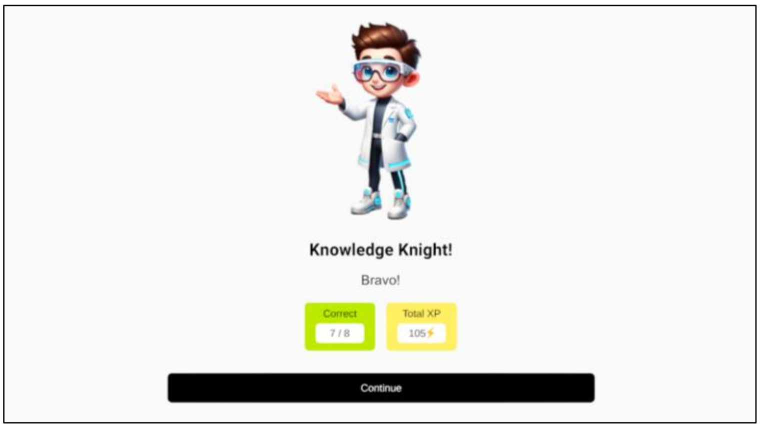


Figure 4.115: End panel's UI

The end panel of the interactive assessment module (Figure 4.115) also includes a display for the total number of correct answers, in addition to the XPDisplayer. This feature provides users with a summary of their performance at the end of the assessment. The overall structure and layout of the interactive assessment module mirror those of the tutorial module, ensuring a consistent user experience while incorporating these key differences.

4.2.6 Gamification Elements Module

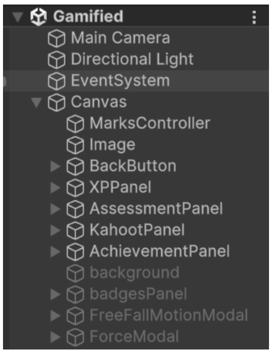


Figure 4.116: Gamified scene's hierarchy

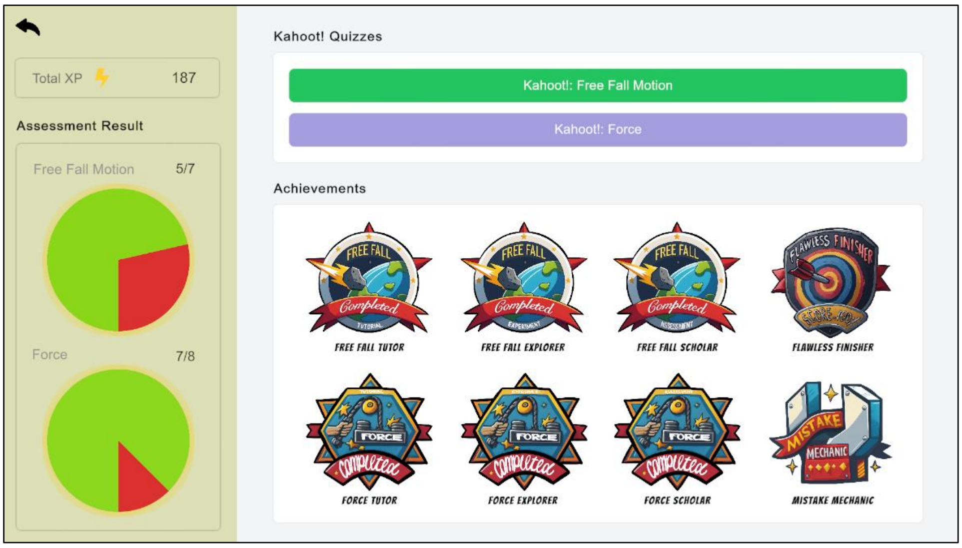


Figure 4.117: Gamified Elements UI

Figure 4.116 shows the hierarchy of the gamified scene, while Figure 4.117 shows the UI. It is divided into 4 sections:

1. **Display of XP**: This section shows the XP points earned by the user throughout the learning modules. The XP points are updated and displayed to reflect the user's progress and achievements.
2. **Display of total correct answers**: This section shows the total number of correct answers given by the user in both the Free Fall Motion and Force interactive assessment modules.
3. **Buttons to Kahoot! Quizzes section**: This section includes buttons that link to the Kahoot quiz section, allowing users to engage in quizzes related to the topics they've studied.
4. **Achievement section**: The achievement section is designed to showcase the 8 badges that users can earn by completing various tasks or reaching specific milestones.

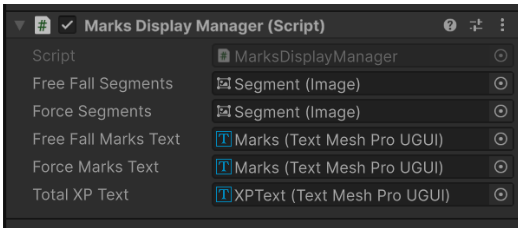


Figure 4.118: Assignments of MarksDisplayManager script in the MarksController object's inspector

```
using UnityEngine;
using UnityEngine.UI;
using TMPro;

public class MarksDisplayManager : MonoBehaviour
{
    public Image freeFallSegments;
    public Image forceSegments;

    public TextMeshProUGUI freeFallMarksText;  // Text component to display Free Fall marks
    public TextMeshProUGUI forceMarksText;     // Text component to display Force marks
    public TextMeshProUGUI totalXPText;         // Text component to display Total XP

    private const string freeFallKey = "CorrectAnswers_FreeFall";  // PlayerPrefs key for Free Fall marks
    private const string forceKey = "CorrectAnswers_Force";        // PlayerPrefs key for Force marks
    private const string totalXPKey = "TotalXP";                   // PlayerPrefs key for Total XP

    private int freeFallMarks;
    private int forceMarks;
    private int totalXP;

    void Start()
    {
        DisplayMarks();
        UpdateChart();
        DisplayTotalXP();
    }

    void DisplayMarks()
    {
        // Retrieve the marks from PlayerPrefs
        freeFallMarks = PlayerPrefs.GetInt(freeFallKey, 0);
        forceMarks = PlayerPrefs.GetInt(forceKey, 0);

        // Update the UI text components
        freeFallMarksText.text = freeFallMarks.ToString() + " / 7";
        forceMarksText.text = forceMarks.ToString() + " / 8";
    }

    // Pass an array of values to create the chart
    void UpdateChart()
    {
        freeFallSegments.fillAmount = (float)freeFallMarks / 7f;
        forceSegments.fillAmount = (float)forceMarks / 8f;
    }

    void DisplayTotalXP()
    {
        // Retrieve the total XP from PlayerPrefs
        totalXP = PlayerPrefs.GetInt(totalXPKey, 0);

        // Update the UI text component for total XP
        totalXPText.text = totalXP.ToString();
    }
}
```

Figure 4.119: MarksDisplayManager script

The main functionality of this MarksDisplayManager script (Figure 4.119) is to retrieve and display the user's performance metrics from saved data (`PlayerPrefs`) in a visual format. Here's a breakdown of the key functionalities:

1. **Display of Free Fall and Force Marks**: The script retrieves the number of correct answers for both the Free Fall and Force assessments from `PlayerPrefs` and updates the corresponding `TextMeshProUGUI` components (`freeFallMarksText` and `forceMarksText`) to display the correct answers out of the total number of questions (7 for Free Fall and 8 for Force).

2. **Update of Segments in the Chart**: It visually represents the user's performance in Free Fall and Force assessments through segment charts (represented by freeFallSegments and forceSegments). The `UpdateChart()` method calculates the proportion of correct answers relative to the total number of questions and adjusts the fill amount of the chart segments accordingly.
3. **Display of Total XP**: The `DisplayTotalXP()` method retrieves the user's total XP from `PlayerPrefs` and updates the `totalXPText` component to display the total XP earned.

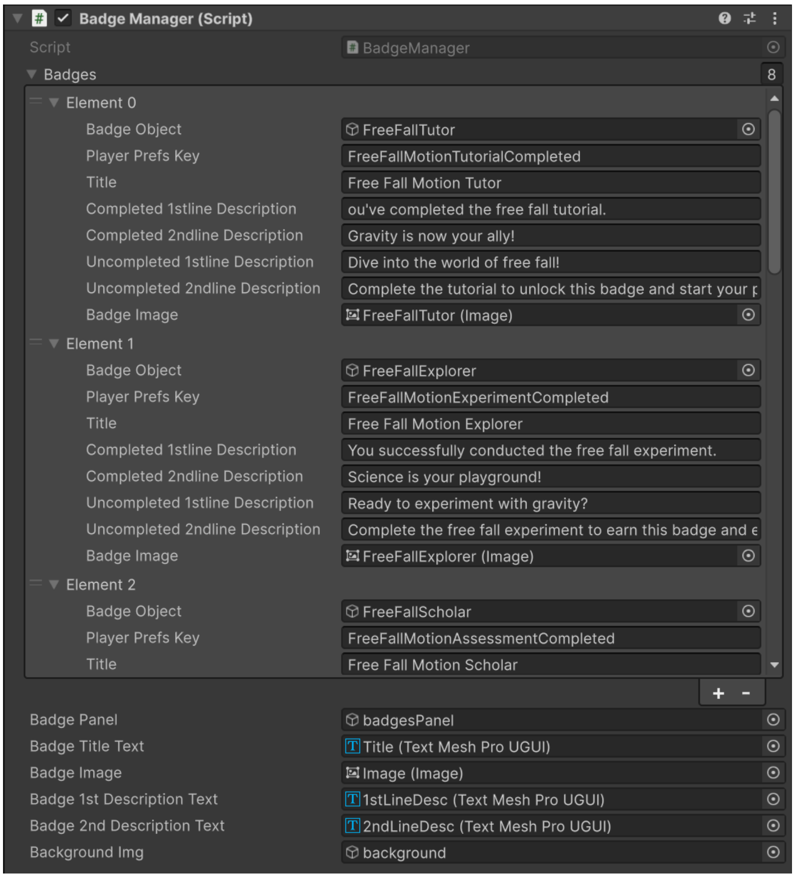


Figure 4.120: Assignments of Badge Manager script in the badgePanel GameObject's inspector

```csharp
using UnityEngine;
using UnityEngine.UI;
using TMPro;

public class BadgeManager : MonoBehaviour
{
    [System.Serializable]
    public class Badge
    {
        public GameObject badgeObject;      // The badge GameObject (UI element)
        public string playerPrefsKey;       // The PlayerPrefs key to check if the badge is achieved
        public string title;
        public string completed1stlineDescription; // Description for the completed badge
        public string completed2ndlineDescription; // Description for the completed badge
        public string uncompleted1stlineDescription; // Description for the uncompleted badge
        public string uncompleted2ndlineDescription; // Description for the uncompleted badge
        public Image badgeImage;            // The Image component for the badge
    }

    public Badge[] badges;                 // Array to hold badges and their corresponding keys
    public GameObject badgePanel;          // The panel to display badge info
    public TextMeshProUGUI badgeTitleText; // The text element for badge title
    public Image badgeImage;
    public TextMeshProUGUI badge1stDescriptionText; // The text element for badge description
    public TextMeshProUGUI badge2ndDescriptionText; // The text element for badge description
    public GameObject backgroundImg;
    private Color achievedColor = Color.white; // Color for achieved badges
    private Color unachievedColor = new Color(203f / 255f, 203f / 255f, 203f / 255f, 188f / 255f); // Color for unachieved badges

    void Start()
    {
        CheckBadges();
    }

    void CheckBadges()
    {
        foreach (Badge badge in badges)
        {
            bool isCompleted = PlayerPrefs.GetInt(badge.playerPrefsKey, 0) == 1;

            // Set badge sprite based on completion status
            badge.badgeImage.color = isCompleted ? achievedColor : unachievedColor;

            // Add a listener to the badge's button component to show the badge panel with details when clicked
            Button badgeButton = badge.badgeObject.GetComponent<Button>();
            if (badgeButton != null)
            {
                badgeButton.onClick.RemoveAllListeners(); // Clear any existing listeners
                badgeButton.onClick.AddListener(() => OnBadgeClicked(badge, isCompleted));
            }
        }
    }

    void OnBadgeClicked(Badge badge, bool isCompleted)
    {
        // Set the title and description based on whether the badge is completed or not
        badgeTitleText.text = badge.title;
        badge1stDescriptionText.text = isCompleted ? badge.completed1stlineDescription : badge.uncompleted1stlineDescription;
        badge2ndDescriptionText.text = isCompleted ? badge.completed2ndlineDescription : badge.uncompleted2ndlineDescription;
        badgeImage.color = isCompleted? achievedColor : unachievedColor;

        // Show the badge panel
        badgePanel.SetActive(true);
        backgroundImg.SetActive(true);
    }

    // Method to close the badge panel
    public void CloseBadgePanel()
    {
        badgePanel.SetActive(false);
        backgroundImg.SetActive(false);
    }
}
```

Figure 4.121: Badge Manager script

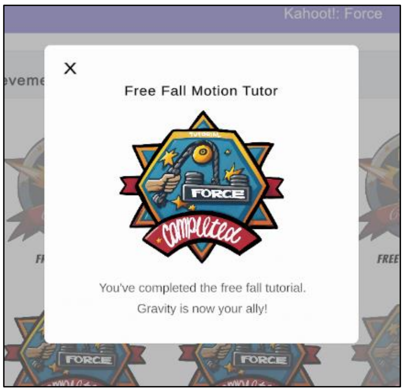


Figure 4.122: Completed badge with congratulations message

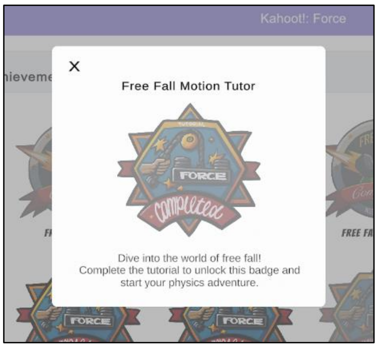


Figure 4.123: Incomplete dimmed badge with encouragement message

The BadgeManager script (Figure 4.121) is responsible for managing and displaying the achievement badges in the game or learning application. It tracks badge achievements, visually indicates which badges are completed or uncompleted, and provides detailed information about each badge when clicked. Here's an explanation of its main functionality:

1. **Badge Class Definition**: The script uses a nested Badge class to represent individual badges. Each Badge has the following properties:
   - `badgeObject`: The UI element that represents the badge.
   - `playerPrefsKey`: The PlayerPrefs key used to store the badge's achievement status (whether it's unlocked or not).
   - `title`: The title of the badge.
   - `completed1stlineDescription` and `completed2ndlineDescription`: The description displayed when the badge is completed.
   - `uncompleted1stlineDescription` and `uncompleted2ndlineDescription`: The description shown when the badge is not yet unlocked.
   - `badgeImage`: The image component used to visually represent the badge.
2. **Checks Badge Status to Assign Badge Colour**: The script retrieves the completion status of each badge by accessing the relevant `PlayerPrefs` key which is updated through the LessonCompletion script in the tutorial, experiment, and assessment modules. If a badge has been achieved, its color is updated to a bright, "achieved" colour to indicate completion. Conversely, if the badge remains unachieved, the script sets it to a dimmed version (a light gray colour), visually signifying its incomplete status. This colour distinction helps users easily identify their progress at a glance.

3. **Displays Badge Information Based on Completion Status**: When a user clicks on any badge, a detailed pop-up panel is displayed, providing the title and description of the badge. The content in the panel dynamically changes based on whether the badge is completed or not. For completed badges, the user is shown a description celebrating their achievement. In contrast, uncompleted badges display an encouragement message to motivate the user to complete the corresponding module. For example, Figure 4.122 illustrates a completed badge with its description, while Figure 4.123 depicts a dimmed badge for an incomplete tutorial module along with an uplifting message urging the user to complete the task. This feature provides both informative feedback and motivation for the user to continue their learning journey.

Figure 4.120 illustrates the assignments of the BadgeManager script within the `badgePanel` GameObject's Inspector. Each of the 8 badge elements is individually configured, requiring specific content for each badge, such as the title, image, first and second line descriptions (for both completed and uncompleted states). Additionally, the script requires UI elements to be assigned, including the text fields for the badge title, descriptions, and the image component. This setup ensures that each badge is properly linked to its respective UI components, allowing dynamic updates based on the user's progress.

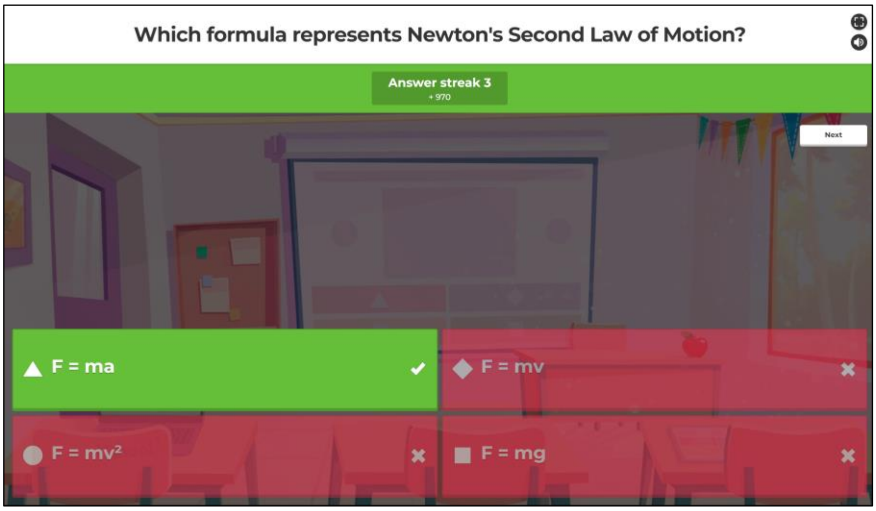


Figure 4.124: Example question with immediate feedback upon answering (in Kahoot!)

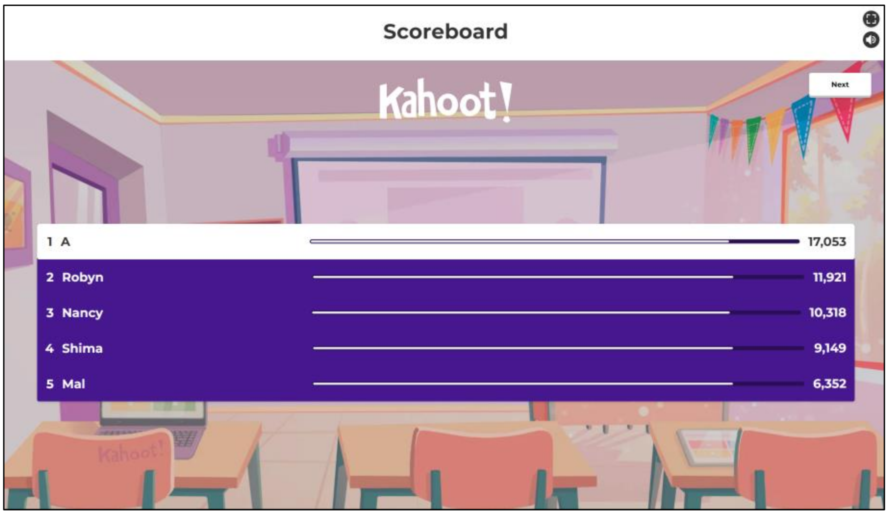


Figure 4.125: Scoreboard of Kahoot!

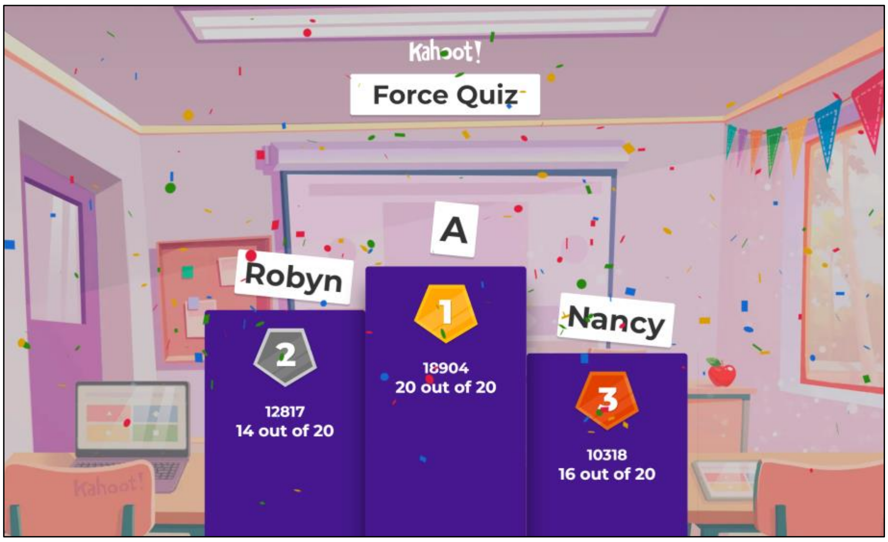


Figure 4.126: Kahoot! quiz's leaderboard

Upon clicking the Kahoot! Quizzes button as illustrated in the UI (Figure 4.117), users are presented with a confirmation panel. Once confirmed, they are directed to the respective Kahoot quiz for either the Force or Free Fall Motion topic, depending on which button was pressed. Figure 4.124 provides an example of a question from the Force topic, highlighting how immediate feedback is given upon answering. During the quiz, the scoreboard, shown in Figure 4.125, periodically updates, giving participants real-time feedback on their progress and maintaining engagement. Upon completion of the quizzes, a leaderboard (Figure 4.126) is displayed, showcasing the top three winners. This feature fosters a sense of achievement and healthy competition among learners, encouraging them to strive for higher performance while reinforcing their understanding of the concepts.

4.2.7 Collaborative Learning Space Module

Upon clicking the collaborative learning icon in the main menu and confirming by selecting the "Join Now" button on the confirmation panel, users are redirected to a custom space on Gather.Town through an external URL.

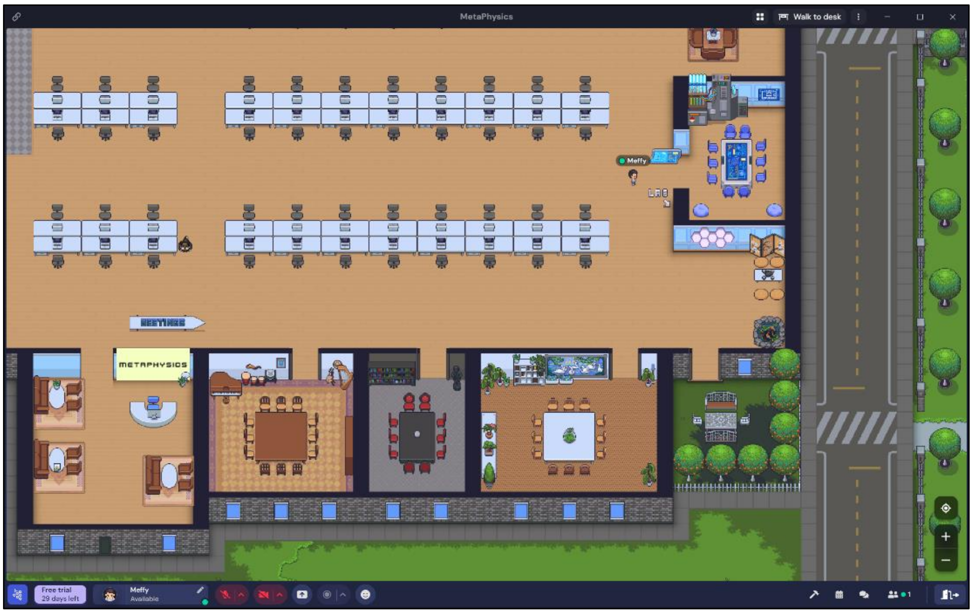


Figure 4.127: MetaPhysics's Gather.Town environment

The Gather.Town-based collaborative learning space, illustrated in Figure 4.127, is designed to facilitate a highly interactive and engaging environment where students and educators can collaborate effectively. It serves multiple purposes: users can engage in discussions, participate in quizzes, perform simulations together, and interact with one another in real time. The virtual environment is carefully tailored to suit an educational setting, complete with features like a digital whiteboard for group brainstorming and problem-solving. Here are some key highlights in this space:

1. **Character Customization**:

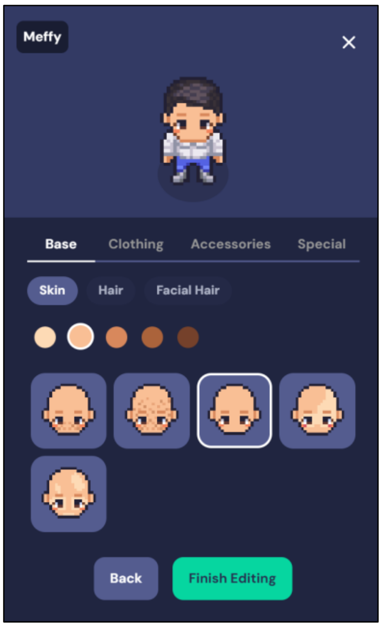


Figure 4.128: Character Modification Panel

Users can create and personalize their avatars, including customization options for skin, hair, clothing, and accessories, illustrated in Figure 4.128, to reflect their individuality.

2. **The Entrance**:

Figure 4.129: The entrance

Upon entry, users are greeted with the application's title and road signs (Figure 4.12) that guide them to various activities within the space.

3. Interaction with Objects:

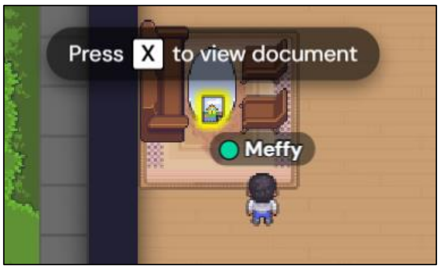


Figure 4.130: Instruction to interact with object

Users can interact with objects by pressing the 'X' key, such as viewing documents (Figure 4.130) or engaging with other interactive elements in the environment.

4. User Interaction:

Figure 4.131: Interaction among users

The platform supports real-time communication through mic and video calls, as well as text messaging as shown in Figure 4.131. Users can converse privately in designated areas or interact with everyone globally.

5. The Physics Lab:

Figure 4.132: The Physics Lab

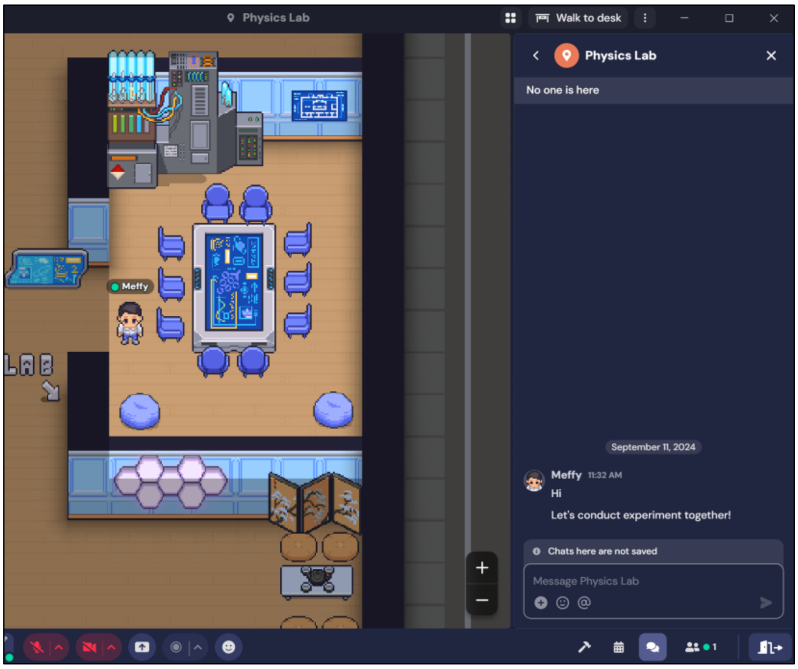


Figure 4.133: Conversation Panel of the Physics Lab

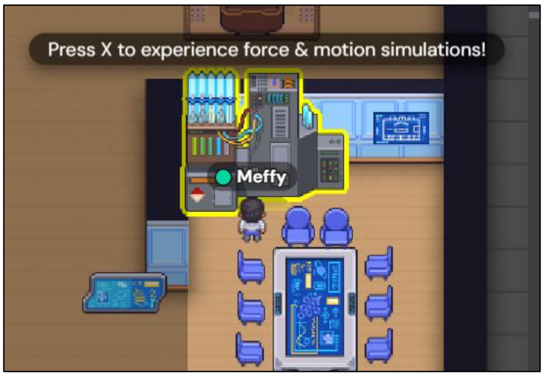


Figure 4.134: Instruction to experience simulations

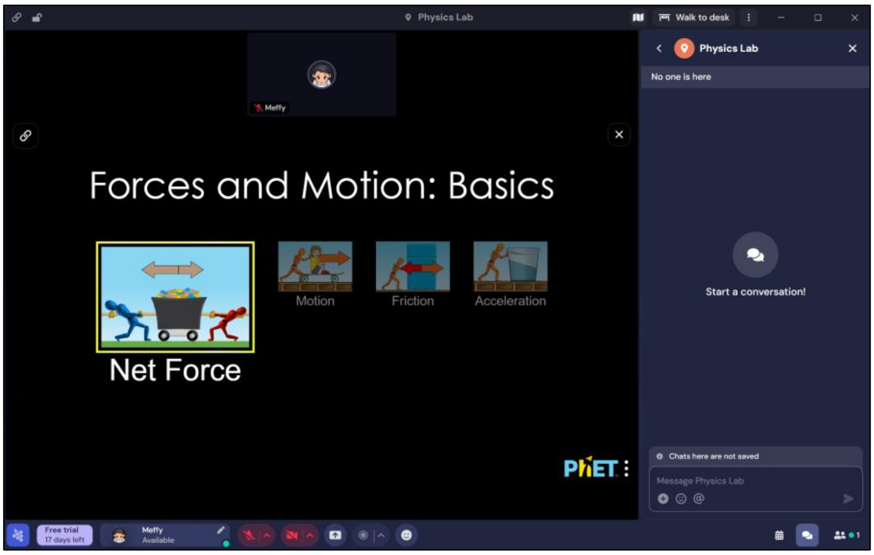


Figure 4.135: The simulations

To enhance the learning experience, the space incorporates PhET simulations, designed with a Physics Lab that mimic the futuristic lab environment (Figure 4.132). Users can conduct Physics experiments collaboratively, fostering a hands-on approach to understanding concepts. Upon entering the lab, a conversation panel as shown in Figure 4.133, facilitates chat communication. Users can interact with the generator object by pressing 'X' to access simulations shown in Figure 4.135.

6. The Discussion Room:

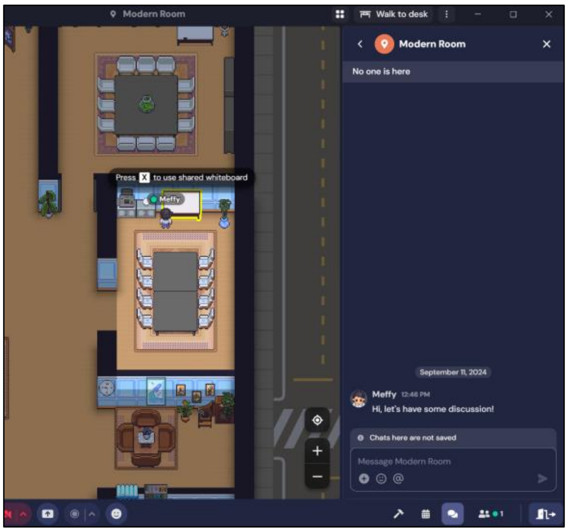


Figure 4.136: The Discussion Room

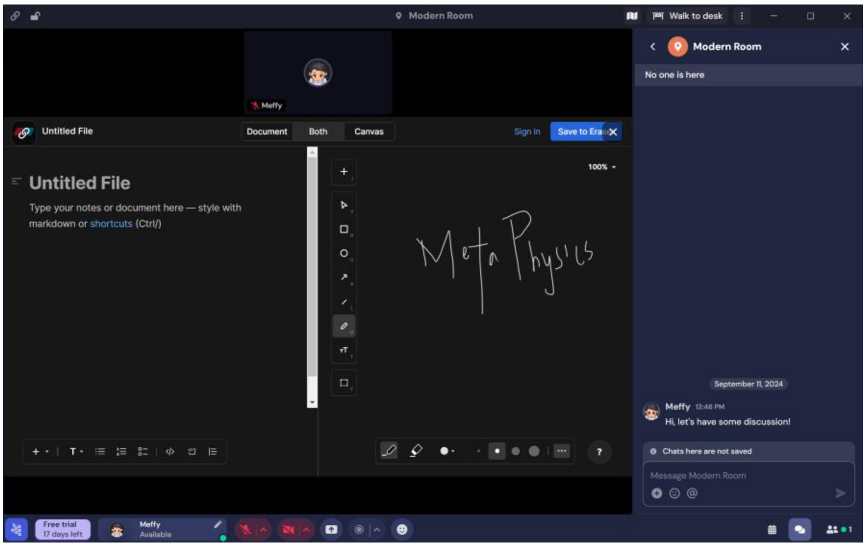


Figure 4.137: The whiteboard

The discussion room (Figure 4.136) includes a whiteboard where multiple users can collaborate on brainstorming and problem-solving activities, as depicted in Figure 4.137.

7. **The Kahoot! Quiz**:

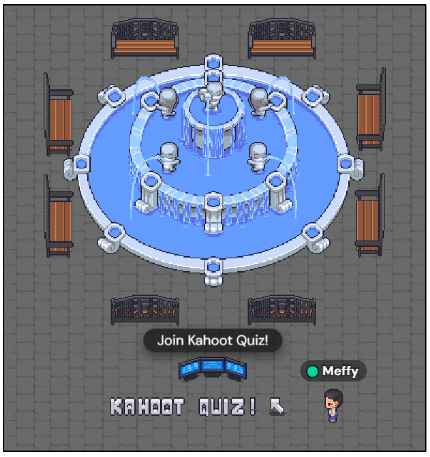


Figure 4.138: Join Kahoot! Quiz's prompt

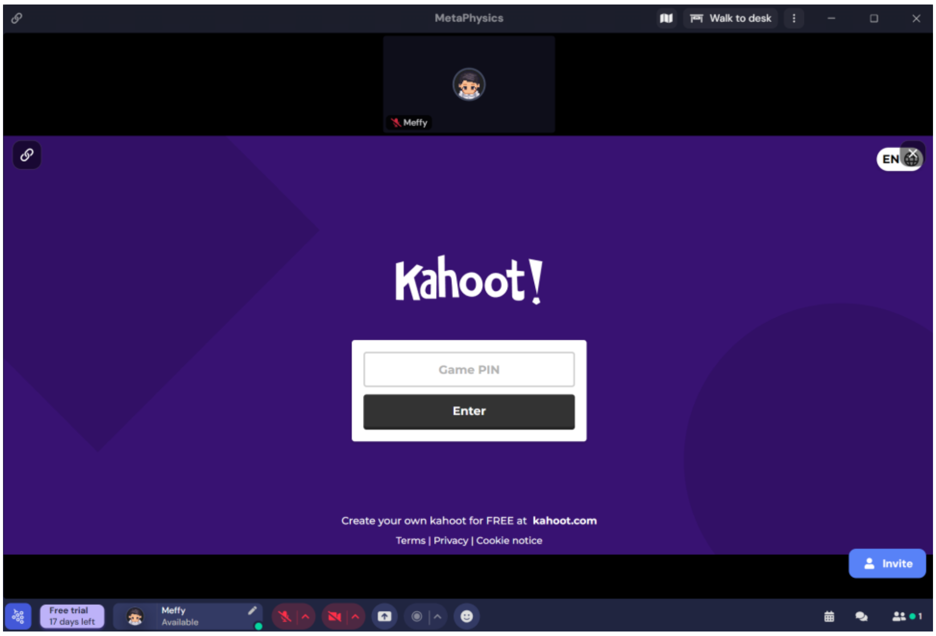


Figure 4.139: The Kahoot! Quiz

Moreover, a Kahoot quiz section which was introduced in the gamification elements module (section 4.2.6), is integrated into the Gather.Town space as shown in Figure 4.138. This feature promotes healthy competition with a leaderboard that tracks performance and encourages users to engage actively in learning activities.

This collaborative space not only promotes peer engagement but also supports immersive learning through simulations and real-time feedback, making it an ideal environment for both group study and interactive learning sessions.

CHAPTER 5

TESTING, RESULTS AND DISCUSSIONS

5.1 Overview

Chapter 5 focuses on the evaluation of the developed system, incorporating testing, result analysis, and discussion. To assess the usability of the system and user satisfaction, two established methods were employed by the author: the System Usability Scale (SUS) and the Post-Study System Usability Questionnaire (PSSUQ). This chapter provides a detailed analysis of the collected data, highlighting key findings and user feedback. These results are discussed in relation to the system’s overall effectiveness, to offer insights into areas of success and potential improvement, ensuring a high-quality and user-friendly learning experience. This chapter also concludes with reflections on the usability testing outcomes and their implications for future system refinement.

5.2 Method of Testing

The testing phase included 20 respondents, comprising students and educators, to assess the application ‘s usability and effectiveness on enhancing learning performance. Two primary instruments were used: the System Usability Scale (SUS) for evaluating overall usability and the Post-Study System Usability Questionnaire (PSSUQ) to measure system usefulness, information quality, and interface quality. Additionally, to evaluate the effectiveness of the platform in enhancing learning performance, assessment scores achieved by participants were gathered from two modules: Free Fall Motion and Force. Participants' feelings toward the platform were also collected through a survey, which included questions about their perceived learning improvement using immersive-based education methods compared to traditional approaches, as well as their comments on the application.

Prior to testing, the author set up a guided environment, where participants received a detailed introduction to the application. The author explained the various modules, functionalities, and provided example scenarios to ensure that all necessary features were thoroughly tested by users.

Participants were asked to complete both the Free Fall and Force assessments, allowing their performance to be evaluated alongside their perceptions of how the platform impacted their learning experience.

Testing was conducted both physically and virtually to accommodate all participants. For virtual testing, some respondents used the "control access" feature in Microsoft Teams (MT) to remotely control the author's laptop and perform testing, while others who were unable to access MT participated by watching a demonstration video of the application.

Upon completing the tests, participants were asked to fill out a Google form that gathered their responses to the SUS and PSSUQ questionnaires, along with feedback or opinions regarding the platform. Participants' assessment results and their reflections on the platform's effectiveness in enhancing learning performance were also gathered through the questionnaires. This collected data provided valuable insights into user satisfaction, learning performance, and potential areas for improvement.

5.2.1 System Usability Scale (SUS)

The System Usability Scale (SUS) was developed by John Brooke in 1986 as a 'quick and dirty' tool for assessing the usability of nearly any type of system (Thomas, 2019). The SUS consists of a 10-item questionnaire with a Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). This method is known for producing statistically valid results with relatively small sample sizes, making it an efficient and cost-effective choice for usability testing.

The SUS score, which usually ranges from 0 to 100, is a composite metric that represents a system's overall usability. Despite its simplicity, SUS has proven to be a reliable method for distinguishing between usable and non-usable systems. It is particularly valuable because it offers a rapid and comprehensive method for evaluating the user experience while delivering clear and useful results.

In the context of this project, SUS testing was conducted after the development phase to gauge the usability of the metaverse-based learning platform. The SUS questionnaire was distributed to 20 respondents, including both students and educators. Participants were recruited through video demonstrations and remote-control sessions to ensure an immersive and realistic testing experience. The resulting SUS score was then analysed to assess the application's user-friendliness and overall effectiveness.

5.2.2 Post-Study System Usability Questionnaire (PSSUQ)

The Post-Study System Usability Questionnaire (PSSUQ) is another crucial tool for evaluating system usability and user satisfaction. Developed by IBM in 1992, the PSSUQ is designed to be given at the end of a usability research (Learn, 2023). Unlike SUS, which focuses on overall usability, PSSUQ provides a more detailed analysis of system quality across three key dimensions: System Usefulness, Information Quality, and Interface Quality. The questionnaire consists of 16 items, each rated on a 7-point scale, allowing for the capture of nuanced user feedback.

PSSUQ is particularly valuable for its ability to provide in-depth insights into specific aspects of a system's usability. This makes it an excellent choice for evaluating complex digital products, such as the metaverse-based learning platform developed in this project. However, its length can pose a risk of respondent fatigue, particularly in longer studies.

For this project, PSSUQ testing was conducted alongside SUS, with the same 20 respondents completing the questionnaire. The participants were recruited through similar methods, ensuring consistency in the testing process. The PSSUQ results were analysed to evaluate the system's usefulness, the quality of information provided, and the effectiveness of the user interface. These insights were then used to identify areas for improvement and to refine the overall user experience.

5.3 Testing Analysis

The testing phase of this project involved a comprehensive evaluation of the metaverse-based learning platform using the System Usability Scale (SUS) and the Post-Study System Usability Questionnaire (PSSUQ). These tools were employed to gather quantitative and qualitative feedback from a diverse group of 20 respondents, including both students and educators, to ensure the system's usability, effectiveness, and user satisfaction.

In addition to system's effectiveness evaluation, participants completed both the Free Fall Motion and Force assessments, allowing for the analysis of their performance through their scores. This provided insight into how effectively the platform enhanced learning performance. Alongside these scores, participants' feelings and perceptions toward the platform, including their views on how immersive-based education impacted their learning of complex Physics concepts compared to traditional methods, were also gathered. These combined data points enabled a more in-depth analysis of both user experience and the platform's educational effectiveness, highlighting key areas of success as well as potential improvements.

5.3.1 System Usability Scale (SUS)

	1		2		3		4		5		6		7		8		9		10		
User:	I think that I would like to use this application frequently	SUS#	I found this application to be unnecessarily complex	SUS#	I thought this application was easy to use	SUS#	I think that I would need the help of a support person to use this application	SUS#	I found the various functions in this app were well integrated	SUS#	I thought there was too much inconsistency	SUS#	I would imagine that most people would learn to use this application very quickly	SUS#	I found this application very cumbersome to use	SUS#	I felt very confident using this application	SUS#	I needed to learn a lot of things before I could get going with this application	SUS#	SUS Score
P1	4	3	2	3	3	2	2	3	4	3	2	3	4	3	2	3	3	2	2	3	70.0
P2	5	4	2	3	4	3	1	4	4	3	1	4	3	2	2	3	3	2	1	4	80.0
P3	3	2	1	4	4	3	1	4	3	2	2	3	4	3	2	3	4	3	2	3	75.0
P4	4	3	2	3	4	3	2	3	4	3	1	4	5	4	1	4	4	3	1	4	85.0
P5	4	3	1	4	5	4	1	4	5	4	1	4	5	4	1	4	5	4	1	4	97.5
P6	5	4	2	3	5	4	1	4	5	4	1	4	5	4	1	4	4	3	1	4	95.0
P7	2	1	3	2	3	2	2	3	3	2	3	2	4	3	3	2	4	3	1	4	60.0
P8	4	3	2	3	4	3	2	3	5	4	1	4	5	4	1	4	5	4	1	4	90.0
P9	5	4	1	4	5	4	1	4	4	3	1	4	5	4	1	4	5	4	1	4	97.5
P10	3	2	3	2	3	2	3	2	4	3	2	3	4	3	2	3	4	3	2	3	65.0
P11	5	4	2	3	4	3	1	4	4	3	1	4	5	4	2	3	4	3	1	4	87.5
P12	5	4	1	4	4	3	1	4	4	3	1	4	5	4	2	3	4	3	1	4	90.0
P13	4	3	1	4	4	3	2	3	3	2	2	3	4	3	3	2	3	2	2	3	70.0
P14	3	2	2	3	3	2	2	3	4	3	2	3	4	3	2	3	3	2	2	3	67.5
P15	4	3	2	3	4	3	1	4	4	3	2	3	5	4	2	3	4	3	1	4	82.5
P16	5	4	1	4	5	4	1	4	5	4	1	4	5	4	1	4	4	3	1	4	97.5
P17	3	2	2	3	4	3	2	3	3	2	3	2	4	3	3	2	4	3	2	3	65.0
P18	4	3	2	3	4	3	2	3	5	4	2	3	5	4	1	4	5	4	1	4	87.5
P19	5	4	1	4	5	4	1	4	4	3	1	4	5	4	2	3	5	4	1	4	95.0
P20	3	2	2	3	3	2	3	2	4	3	3	2	4	3	2	3	4	3	2	3	65.0

Figure 5.1: SUS Results

Figure 5.1 shows the System Usability Scale (SUS) results extracted from Google Form questionnaire filled by participants. In the SUS questionnaire, each question is rated on a scale from 1 to 5, where 1 signifies 'strongly disagree' and 5 signifies 'strongly agree'. The final score for the 10 questions is calculated using a unique method. Below is an overview of the method used in calculating the SUS score:

1. **Scoring Odd-Numbered Questions**: For each of the odd-numbered questions (1, 3, 5, 7, 9), subtract 1 from the score provided by the respondent.
2. **Scoring Even-Numbered Questions**: For each of the even-numbered questions (2, 4, 6, 8, 10), subtract the respondent's score from 5.

3. **Calculating the Total Score**: After adjusting the scores as outlined above, add up all the resulting values. The sum of these values is then multiplied by 2.5 to obtain the overall SUS score for each respondent.
   - **Formula**:

     Per Participant Calculation

     $= [(\sum(OddNumberedScores - 1)) + (25 - \sum(EvenNumberedScores))]\ x\ 2.5$

4. **Final SUS Score**: The SUS score is then calculated by averaging the total scores from all respondents.
   - **Formula**: Total SUS Score

     = AVERAGE (Total Scores from all respondents)

5. **Assigning a Grade**: Based on the SUS score in Figure 5.2, assign a grade using the following grading table:

SUS Score	Grade	Adjective Rating
> 80.3	A	Excellent
68 – 80.3	B	Good
68	C	Okay
51 – 68	D	Poor
< 51	F	Awful

Figure 5.2: SUS Grade Table

Source: Alathas (2018)

This method ensures that not only provides a precise quantitative assessment of the system's usability, measured on a scale from 0 to 100, but also offers a qualitative classification that facilitates clearer interpretation and more actionable insights.

5.3.2 Post-Study System Usability Questionnaire (PSSUQ)

User:	1 Overall, I am satisfied with how easy it is to use this system.	2 It was simple to use this system.	3 I was able to complete the tasks and scenarios quickly using this system	4 I felt comfortable using this system.	5 It was easy to learn to use this system.	6 I believe I could become productive quickly using this system.	7 The system gave error messages that clearly told me how to fix problems.	8 Whenever I made a mistake using the system, I could recover easily and	9 The information (such as on-line help, on-screen messages and other documentati	10 It was easy to find the information I needed.	11 The information provided for the system was easy to understand.	12 The organization of information on the system screens was clear	13 The interface of this system was pleasant.	14 I liked using the interface of this system.	15 This system has all the functions and capabilities I expect it to have	16 Overall, I am satisfied with this system.	Overall	SYSUSE	INFOQUAL	INTERQUAL
P1	1	1	1	2	1	2	3	2	2	2	1	2	2	2	2	1	1.69	1.33	2.00	2.00
P2	2	1	2	2	2	3	2	1	1	2	1	1	2	2	3	2	1.81	2.00	1.33	2.33
P3	2	2	2	2	2	3	2	1	2	1	2	2	1	1	2	2	1.81	2.17	1.67	1.33
P4	3	2	2	3	2	3	1	2	2	2	1	1	2	2	3	2	2.06	2.50	1.50	2.33
P5	2	2	1	2	1	2	2	1	1	2	1	2	2	2	2	3	1.75	1.67	1.50	2.00
P6	3	2	3	2	1	3	2	1	2	1	1	1	3	2	2	3	2.00	2.33	1.33	2.33
P7	4	3	3	3	3	4	3	2	2	2	2	3	2	2	2	3	2.69	3.33	2.33	2.00
P8	1	2	2	1	2	2	3	2	2	2	1	1	1	1	3	2	1.75	1.67	1.83	1.67
P9	1	1	2	2	1	2	2	1	1	1	1	2	1	1	2	1	1.38	1.50	1.33	1.33
P10	3	2	2	3	3	4	2	2	2	3	2	2	1	2	2	2	2.31	2.83	2.17	1.67
P11	1	1	2	2	2	3	1	1	1	1	1	1	2	2	1	1	1.44	1.83	1.00	1.67
P12	3	2	4	3	2	4	2	1	2	1	3	2	3	3	3	3	2.56	3.00	1.83	3.00
P13	2	2	1	2	2	3	1	2	2	2	2	1	1	2	2	2	1.81	2.00	1.67	1.67
P14	3	2	2	2	3	3	1	2	1	2	1	2	1	2	3	2	2.00	2.50	1.50	2.00
P15	2	2	2	2	2	2	2	1	1	1	2	1	1	2	2	2	1.69	2.00	1.33	1.67
P16	1	1	2	2	1	1	1	1	1	2	3	2	1	1	1	1	1.38	1.33	1.67	1.00
P17	4	2	3	3	3	3	3	2	2	3	2	3	2	3	2	3	2.69	3.00	2.50	2.33
P18	2	1	3	2	2	3	3	2	1	2	2	2	2	2	1	1	1.94	2.17	2.00	1.67
P19	1	1	2	1	1	2	2	1	1	1	1	1	2	2	1	1	1.31	1.33	1.17	1.67
P20	2	2	1	2	1	3	3	2	2	2	2	2	1	2	2	2	1.94	1.83	2.17	1.67

Figure 5.3: PSSUQ Results

Figure 5.3 shows the results of Post-Study System Usability Questionnaire (PSSUQ) extracted from Google Form questionnaire filled by participants. In the PSSUQ questionnaire, each question is rated on a scale from 1 to 7, where 1 indicates 'strongly agree' and 7 indicates 'strongly disagree'. The PSSUQ evaluates four key areas:

- Overall: the average scores of questions 1 to 16
- System Usefulness (SYSUSE): the average scores of questions 1 to 6
- Information Quality (INFOQUAL): the average scores of questions 7 to 12
- Interface Quality (INTERQUAL): the average scores of questions 13 to 15

The scores are calculated as follows:

1. **Calculating the Scores**: the average scores for the Overall (Figure 5.4), SYSUSE (Figure 5.5), INFOQUAL (Figure 5.6), and INTERQUAL (Figure 5.7) scales of each participant is calculated based on their responses.
    - **Formula**:

      Per Participant Calculation (e.g. User P1 in excel)

Figure 5.4: Overall Score of User P1

Figure 5.5: SYSUSE Score of User P1

Figure 5.6: INFOQUAL Score of User P1

Figure 5.7: INTERQUAL Score of User P1

2. **Aggregating Scores**: Each key area in the PSSUQ is then assessed by calculating the average of the total scores provided by all respondents for the Overall (Figure 5.8), SYSUSE (Figure 5.9), INFOQUAL (Figure 5.10), and INTERQUAL (Figure 5.11) dimensions.

Figure 5.8: Average Overall Usability Score

Figure 5.9: Average System Usefulness (SYSUSE) Score

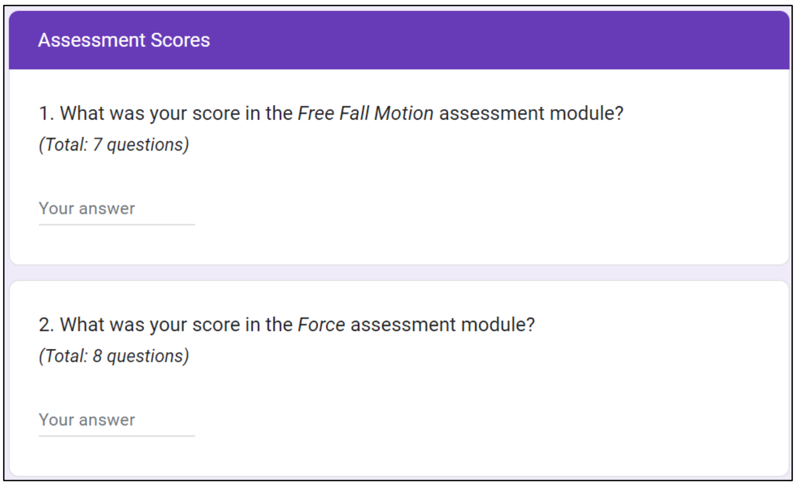
Figure 5.10: Average Information Quality (INFOQUAL) Score

Figure 5.11: Average Interface Quality (INTERQUAL) Score

3. **Comparing with Reference Scores**: Compare the aggregated scores to the reference scores provided by Sauro and Lewis (2016) to assess how the system's usability compares to established benchmarks.
    - **Reference scores**:
        - SYSUSE: 2.80
        - INFOQUAL: 3.02
        - INTERQUAL: 2.49
        - Overall: 2.82

This method ensures that each participant's feedback is accurately reflected in the overall analysis, providing a comprehensive view of the system's usability, information quality, and interface quality.

5.3.3 Participants’ Learning Performance


Assessment Scores

1. What was your score in the *Free Fall Motion* assessment module?
(Total: 7 questions)

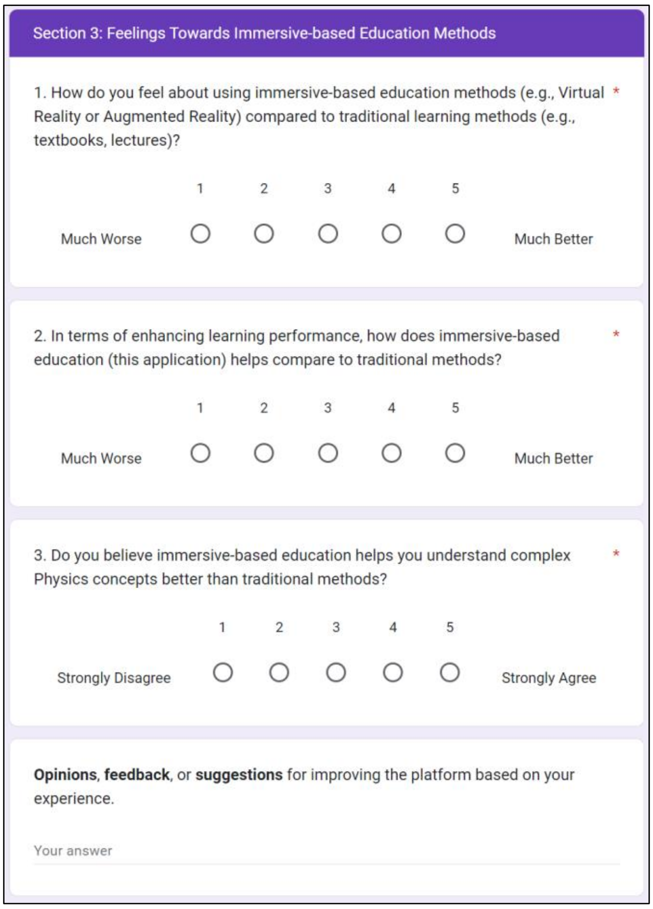
Your answer

2. What was your score in the *Force* assessment module?
(Total: 8 questions)

Your answer

Figure 5.12: Assessment scores questions in google form

As part of the testing, participants were required to go through both the Free Fall Motion and Force assessments. Each assessment was designed to evaluate their understanding of the concepts after interacting with the corresponding modules. The Free Fall Motion assessment had a total score of 7 points, while the Force assessment had a total score of 8 points. The assessment results for the Free Fall Motion and Force topics were analysed based on the total scores obtained by participants through google form as shown in Figure 5.12. The results were visualized using a graph generated from google form, and the performance results were analysed and evaluated to determine the effectiveness of the platform in enhancing students' learning performance.


Section 3: Feelings Towards Immersive-based Education Methods

1. How do you feel about using immersive-based education methods (e.g., Virtual Reality or Augmented Reality) compared to traditional learning methods (e.g., textbooks, lectures)? *

	1	2	3	4	5	
Much Worse	○	○	○	○	○	Much Better

2. In terms of enhancing learning performance, how does immersive-based education (this application) helps compare to traditional methods? *

	1	2	3	4	5	
Much Worse	○	○	○	○	○	Much Better

3. Do you believe immersive-based education helps you understand complex Physics concepts better than traditional methods? *

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

Opinions, **feedback**, or **suggestions** for improving the platform based on your experience.

Your answer

Figure 5.13: Google Form questions on participants' feelings towards the platform

The analysis of participants' experiences with the immersive-based education platform involved both quantitative and qualitative approaches, where the data were collected using questionnaire as shown in Figure 5.13. Quantitative data were collected using a 5-point Likert scale for three key aspects: feelings toward immersive-based education compared to traditional methods, perceived effectiveness in enhancing learning performance, and the ability of the platform to aid in understanding complex Physics concepts. The responses for each question were summarized using descriptive statistics generated from google form, including the frequency and percentage distribution across different rating levels (1 = strongly disagree to 5 = strongly agree). For each aspect, responses were categorized into groups, allowing for an aggregated view of the overall sentiment.

Qualitative data were gathered from open-ended questions, where participants provided feedback on their general experience. This feedback was analysed using thematic analysis to identify common themes, which were grouped into categories such as ease of use, onboarding suggestions, interface design, and content quality. These qualitative insights were further used to interpret and support the findings from the quantitative analysis, providing a comprehensive view of user experiences and potential areas for improvement.

5.4 Results and Discussions

A total of 20 individuals participated in the evaluation and testing of this project's usability, effectiveness, and user satisfaction, providing valuable feedback through the System Usability Scale (SUS) and the Post-Study System Usability Questionnaire (PSSUQ). Participants also completed the Free Fall Motion and Force assessments, enabling the analysis of their performance and understanding of the platform's educational effectiveness.

The findings from both the usability assessments and the performance scores, alongside qualitative feedback regarding their experiences with the application, provide a comprehensive view of how the platform facilitates learning in Physics. This analysis not only sheds light on the overall satisfaction and engagement of users but also highlights how immersive-based education methods can enhance understanding of complex Physics concepts compared to traditional teaching methods. The integration of quantitative and qualitative data will allow for a well-rounded discussion on the strengths and areas for improvement within the platform.

Testing Methods	**Scores**
System Usability Scale (SUS)	81.1
Post-Study System Usability Questionnaire (PSSUQ)	
System Usefulness (SYSUSE)	2.12
Information Quality (INFOQUAL)	1.69
Interface Quality (INTERQUAL)	1.87
Overall	1.90

Table 5.1: Testing Scores

The analysis of these scores, as shown in Table 5.1, offers critical insights into the project's performance and user response.

5.4.1 System Usability Scale (SUS)

According to the System Usability Scale (SUS) grading system, the resulting SUS score of 81.1 places the platform in the "Excellent" grade category, signifying a high level of user satisfaction and ease of use.

This exceptional score reflects the platform's effectiveness in delivering a user-friendly and intuitive learning experience. The high SUS score indicates that the platform is well-received by its target audience, aligning with expectations for usability and functionality. The "A" grade underscores the platform's strong performance, which is crucial for fostering student engagement and enhancing learning performances.

5.4.2 Post-Study System Usability Questionnaire (PSSUQ)

The PSSUQ scores as shown in Table 5.1 indicate that the platform was highly regarded across all dimensions, with particularly strong scores in System Usefulness and Interface Quality. In the context of PSSUQ, the low average scores across these dimensions suggest that users found the platform to be highly functional, with a well-designed interface and valuable information, further reinforcing the positive findings from the SUS.

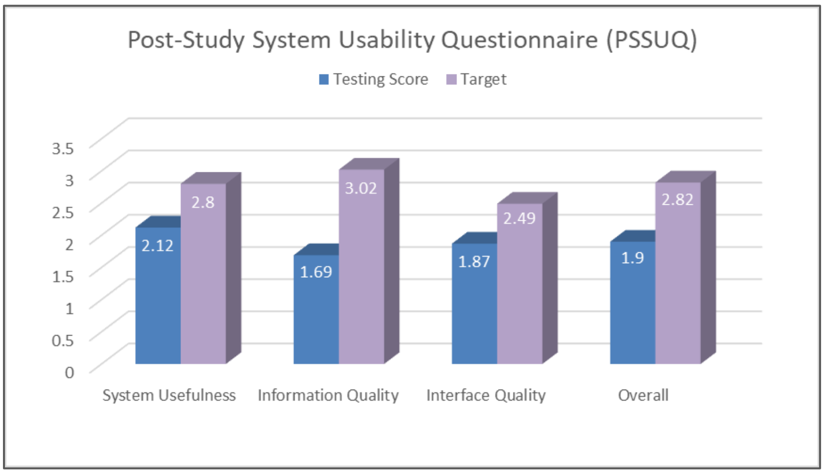


Figure 5.14: Comparison of PSSUQ Results

Source: Created by the author

When compared to the reference scores provided by Sauro and Lewis (2016) as shown in Figure 5.14, the platform's PSSUQ scores align with high usability standards, confirming that it delivers a positive and satisfactory user experience. The feedback gathered through the PSSUQ highlights the platform's strengths in facilitating learning and engagement, while also identifying potential areas for further enhancement. The findings of each dimension are as follow:

- **System Usefulness (SYSUSE):** The SYSUSE score, which evaluates how well the platform supports users in completing their tasks and achieving educational goals, was 2.12. Although slightly higher than other dimensions, this score still indicates that the users found the platform effective in enhancing their learning experience. High system usefulness is essential, as it confirms that the platform not only functions correctly but also provides significant educational value, which is the foundation of any educational tool. Despite the positive score, there is room for improvement, particularly in terms of refining the interactive features and ensuring that the platform meets the varied needs of both students and educators more efficiently.
- **Information Quality (INFOQUAL):** The platform's Information Quality scored the lowest at 1.69, which is notably strong. This score reflects how well the platform communicates the necessary information, such as instructions, tutorials, and content, to users. The high score suggests that users found the information clear, relevant, and easy to understand. The platform’s capacity to deliver Physics concepts accurately, paired with interactive MR experiences, greatly contributed to this score. However, further refining how information is presented in more complex scenarios could enhance this aspect even more.
- **Interface Quality (INTERQUAL):** The "Interface Quality" dimension scored at 1.87, which is a highly favourable result, indicating that users were particularly satisfied with the platform's intuitive interface and responsive design. This dimension measures user satisfaction with the visual attractiveness, layout, and ease of interaction with the user interface. A low score in this area shows that users found the interface to be visually appealing, logically structured, and easy to navigate. Good interface quality enhances the overall learning experience by keeping users engaged and making the platform pleasant to use, which is essential for retaining users and encouraging repeated use. Still, there may be potential to optimize certain design elements and interactions to make the platform even more

user-friendly, particularly for first-time users or those unfamiliar with immersive technologies.

- **Overall Usability:** The "Overall Usability" score averaged at 1.9, surpassing standard benchmarks for usability and user satisfaction. This strong result suggests that users found the platform generally easy to use and satisfactory in meeting their needs. The positive overall usability rating demonstrates the effectiveness of the metaverse-based platform in achieving its educational goals while providing an engaging and accessible experience for users, which is crucial for educational applications where ease of use directly impacts learning engagement and retention.

The Post-Study System Usability Questionnaire (PSSUQ) results for the metaverse-based Physics learning platform were highly positive. Notably, the Information Quality (INFOQUAL) dimension reveals exceptional user satisfaction, highlighting that users found the platform's information clear and relevant, showcasing the platform’s strength in platform’s strength in communicating complex Physics concepts and making abstract ideas accessible to learners. The Interface Quality (INTERQUAL) and Overall scores also reflect strong positive feedback, demonstrating the interface’s effectiveness in providing a visually appealing, well-structured, and immersive user experience, though minor design optimizations could further enhance usability. However, the System Usefulness (SYSUSE) dimension, while still receiving favourable ratings, points to an area with potential for improvement. This suggests that while the platform effectively supports users in completing their learning tasks, there is an opportunity to further refine the system to accommodate a broader range of user needs. Overall, the PSSUQ feedback underscores the platform’s capability to fulfil its educational purpose with a user-centered design that enhances learning performance. The insights gathered provide a clear path for future improvements to maintain and elevate high standards of usability and user engagement.

5.4.3 Evaluation of Effectiveness of MR technologies on Participants' Learning Performance in Physics Education

1. Assessment Scores Achieved by Participants

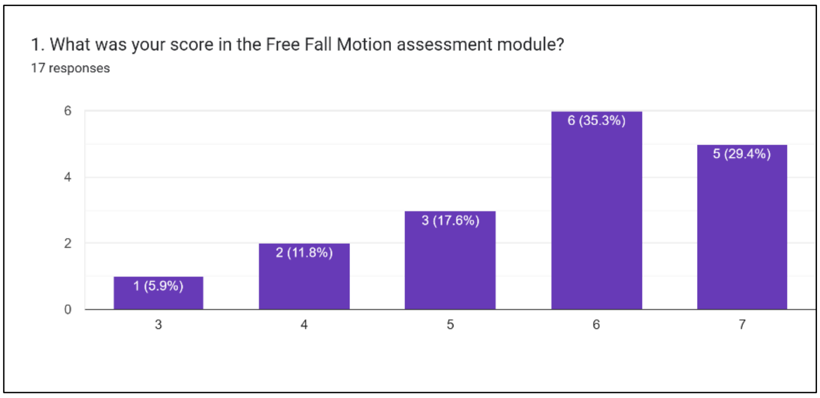


Figure 5.15: Respondents' scores for Free Fall Motion assessment module

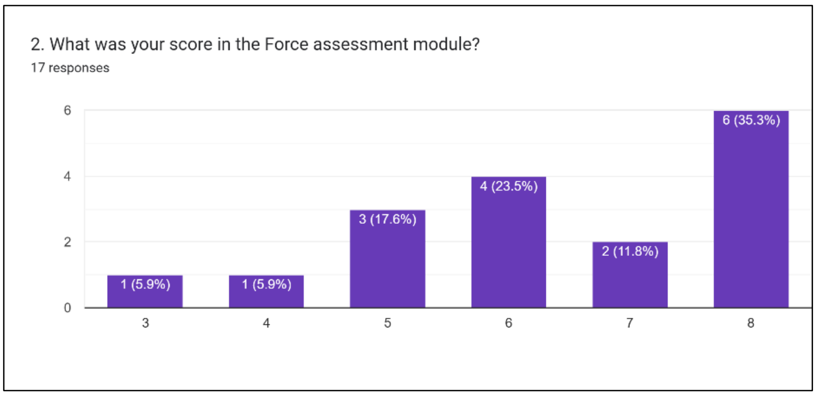


Figure 5.16: Respondents' scores for Force assessment module

Figure 5.15 and 5.16 illustrate the distribution of respondents' scores for the Free Fall Motion and Force assessment modules, where the full marks for Free Fall Motion are 7 and for Force are 8.

In the Free Fall Motion module (Figure 5.15), most respondents scored either 6 marks (35.3%) or 7 marks (29.4%), indicating a strong grasp of the topic. Lower scores (3 to 5 marks) accounted for the rest, with 5 marks at 17.6%, 4 marks at 11.8%, and 3 marks at 5.9%.

In the Force module (Figure 5.16), the highest percentage of respondents (35.3%) achieved the top score of 8 marks. A smaller portion scored 7 marks (11.8%) and 6 marks (23.5%), followed by 5 marks (17.6%), while the lower scores (3 to 4 marks) represented only 5.9% each.

The assessment results for both the Free Fall Motion and Force modules suggest that mixed reality (MR) technologies have a positive impact on students' understanding and learning performance in Physics education.

High Achievers (6 to 8 marks): For the Free Fall Motion assessment, a significant portion of respondents performed well, with 64.7% scoring 6 or 7 marks. Similarly, for the Force assessment, 70.6% scored 6 or above. This indicates that the MR platform was particularly effective in helping the majority of students grasp and apply concepts in both topics, as most respondents performed in the upper range.

Mid-Range Performance (4 to 5 marks): In both assessments, 29.4% of respondents in the Free Fall Motion module and 23.5% in the Force module scored in the range of 4 to 5 marks. This group, while still performing reasonably well, may benefit from additional features such as enhanced feedback, interactive tutorials, or more visual aids to deepen their understanding and improve performance.

Lower Scores (3 marks): In both Free Fall Motion and Force module, 5.9% of respondents scored in the lower range of 3 marks. This small percentage of lower-performing participants may indicate some difficulties in understanding specific concepts. To address this, the platform could consider adding more scaffolded learning steps, simplified explanations, or additional instructional support within the immersive environment.

Overall, the majority of respondents achieved mid-to-high scores in both assessments, reflecting the effectiveness of the MR platform in enhancing learning performance in Physics. The immersive nature of the platform likely helped participants better visualize abstract concepts, leading to improved comprehension and application of both Free Fall Motion and Force principles.

To further improve effectiveness, especially for those who scored lower, incorporating additional interactive elements, guided explanations, and feedback mechanisms could help strengthen learning performance and ensure that all users benefit fully from the immersive experience.

2. Feelings about Immersive-Based Education (compared to traditional methods)

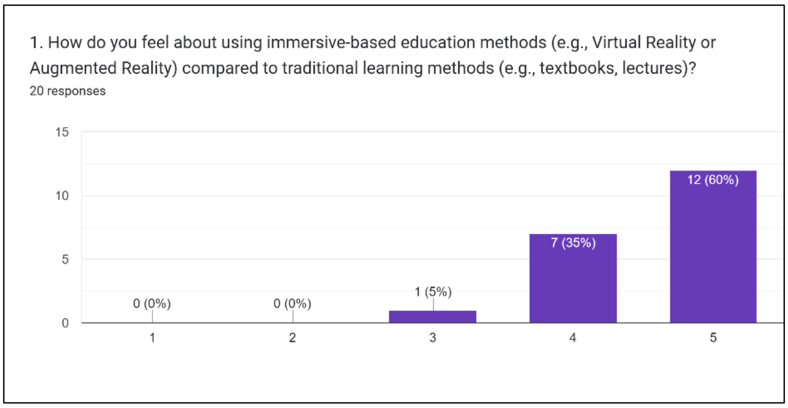


Figure 5.17: Result about participants' feelings towards immersive-based education methods

Figure 5.17 shows the result about participants' feelings towards immersive-based education methods. Out of 20 participants, 95% had a positive perception of immersive-based education, with 60% rating it a "5" (strongly positive) and 35% rating it a "4" (positive). Only 5% gave a neutral response with a rating of "3", and no participants rated it below a 3. These results indicate that most participants view immersive-based education methods favourably compared to traditional methods.

These findings suggest that the shift from traditional learning methods, like textbooks and lectures, to immersive learning technologies (e.g., VR, AR) is well-received. This is consistent with previous research highlighting the potential of immersive technologies to increase engagement and motivation in learners. The strong positive response may also reflect the novelty of the approach and its perceived relevance in modern education. However, the single neutral response suggests that the immersive approach might not appeal to everyone, potentially due to personal preferences or the need for more user-friendly navigation.

3. Effectiveness of Immersive-Based Education in Enhancing Learning Performance

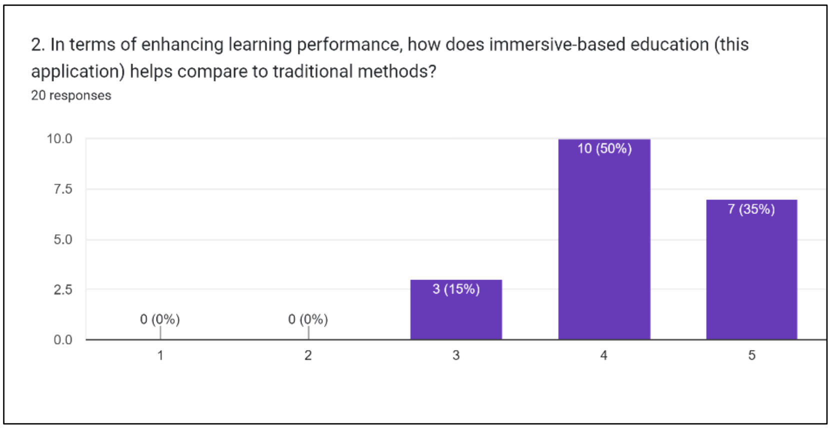


Figure 5.18: Result about participants' opinion on the effectiveness of the platform

Figure 5.18 shows the result about participants' ratings on the effectiveness of immersive-based education in improving learning performance. Participants rated the effectiveness of immersive-based education in improving learning performance positively, with 50% selecting "4" and 35% selecting "5". Meanwhile, 15% rated the effectiveness as "3", indicating a neutral stance. There were no negative ratings (1 or 2).

The majority of participants believe that immersive-based education effectively enhances learning performance, which aligns with its interactive and experiential nature. Immersive technology allows learners to engage with content more actively, improving retention and comprehension, as well as better visualisation of abstract Physics concepts. The 15% neutral response could be due to the learning curve associated with using new technology, as indicated in the feedback about onboarding challenges and interface usability. Overall, these results point toward immersive technologies being a promising tool for learning, though improvements in user experience may further boost perceptions of effectiveness.

4. Understanding of Complex Physics Concepts

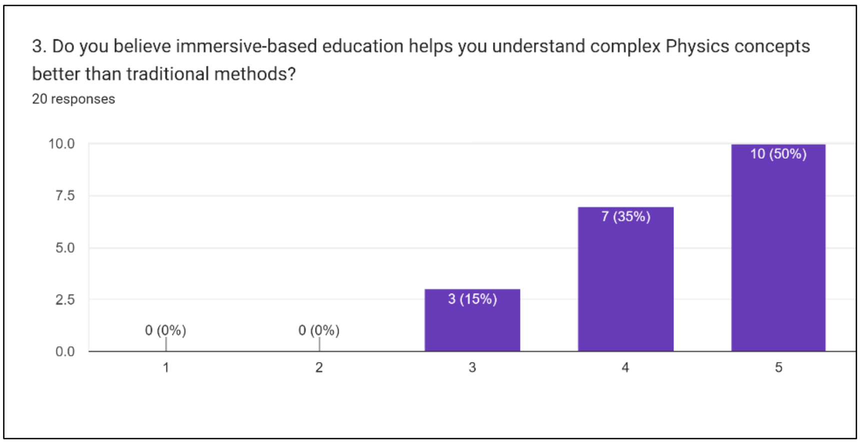


Figure 5.19: Result of participants' belief that this platform helped better understand complex concepts

When asked whether immersive-based education helps in understanding complex Physics concepts, 50% of participants selected "5" (strong agreement), 35% selected "4" (agreement), and 15% selected "3" (neutral). No participant rated below "3". The result is illustrated in Figure 5.19.

The findings indicate that immersive technologies are highly effective in aiding the understanding of abstract Physics concepts, such as free fall and force, which are often difficult to visualize through traditional methods. The high percentage of participants giving a rating of "4" and "5" underscores the potential of these technologies to bridge the gap between theoretical concepts and practical understanding. However, the neutral response might reflect the technical challenges some users faced, such as getting accustomed to the controls, which could have temporarily hindered their learning experience.

5. General Feedback and Suggestions for Improving the Platform

Opinions, feedback, or suggestions for improving the platform based on your experience.
I enjoyed the hands-on experiments. Adding more variety in force and motion examples could enhance learning.
great use of mixed reality for Physics
The information provided is clear, I love the app so much, it's new and interesting for me
the app is impressive, prefer a mobile-friendly version
Exciting app! Look forward to more Physics topics!
The VR experiment is fun
It was difficult to navigate at first; maybe add an onboarding guide or walkthrough
Love the immersive experience, it's new to me ^^
User friendly interface, an even more lively and smooth interface would greatly enhance the experience
Would look to see a simple step by step tutorial to guide new user about the usage of the app
Recommend adding more complex topics
Enjoyable experience, though the assessment could be more challenging.
Immersive tech really helped visualize concepts
Immersive but took a bit to get used to the controls.
would love to see more additional content to enhance my Physics in other topics as well ^^
Great learning aid!
The hands-on experience is what sets this apart. Interestingggg
a bit lacky due to internet connection i guess since im using the control access features, but the app is indeed fun for learning !
Video demo was helpful, I believe this could improve my students' learning performance! Looking forward for broader topic coverage!
Great visuals, but limited by not being able to test directly. Hopefully this app will improve to cover more topics and more smoothly, to be available to market and use in our school =P

Figure 5.20: Opinions, feedback or suggestions from participants

Qualitative feedback (as shown in Figure 5.20) highlighted both strengths and areas for improvement. Common positive themes included the hands-on experience, engaging visuals, and overall fun of the platform. However, some participants mentioned difficulties navigating the interface initially and suggested adding an onboarding guide or tutorial to assist new users. Other feedback emphasized the need for more Physics topics and suggested making the assessments more challenging.

The general feedback aligns with the quantitative data showing strong approval of immersive-based education. Participants appreciated the interactive nature of the platform, which mirrors the high ratings for understanding and engagement. However, the feedback also reveals that improving the user interface and offering additional guidance for first-time users could significantly enhance the experience. This suggests that future iterations of the platform should focus on smoother onboarding, more topics, and possibly more advanced content for users seeking additional challenges. Incorporating these changes could further boost the platform's effectiveness and user satisfaction, leading to broader adoption.

Overall, these results indicate that the use of immersive technology is seen as a promising and effective approach to improving Physics education, particularly in enhancing learning performance and helping students understand complex concepts.

The results and discussions from this study indicate that immersive-based learning, as implemented in the metaverse-based Physics learning platform, significantly enhances user engagement and understanding of complex Physics concepts, particularly in free fall motion and force. The high usability scores from the SUS and PSSUQ questionnaires suggest that the platform is user-friendly and satisfactorily meets the needs of both students and educators. Participants consistently expressed that the immersive nature of the platform helped bridge the gap between abstract concepts and practical understanding, a key challenge in traditional learning methods. The assessment results further demonstrated that users could effectively grasp and apply Physics concepts, supporting the effectiveness of immersive technology in improving learning performance. These findings highlight the potential of immersive-based education to complement and enhance traditional methods, providing a more interactive and engaging learning experience.

CHAPTER 6

CONCLUSION

6.1 Overview

This project aimed to develop an interactive and immersive Physics learning application with a specific focus on the Free Fall Motion and Force topics from the Malaysia KSSM Form 4 syllabus. By leveraging mixed reality (MR), the application sought to enhance user engagement and facilitate the understanding of fundamental Physics concepts. This conclusion provides an overview of the project, highlights the research findings, discusses technical challenges encountered, outlines the knowledge gained, addresses the project's limitations, and proposes potential future improvements. The main objective of this project was to address the challenges students face in comprehending abstract Physics concepts by introducing an immersive, hands-on learning experience. The developed learning platform includes interactive modules that simulate real-life Physics experiments in a virtual environment, allowing students to visualize and manipulate variables in ways that would be difficult or impossible in traditional classroom settings.

6.2 Research Findings

The research findings align closely with the project's objectives and problem statements. The development and testing of the metaverse-based Physics learning platform demonstrated the potential of mixed reality (MR) technologies to overcome several key challenges in traditional Physics education.

6.2.1 Objective 1: To study the use of mixed reality technologies in Physics education through a constructivist approach

The study and implementation of mixed reality (MR) technologies revealed that immersive environments significantly enhance students' ability to engage with abstract Physics concepts concepts in a more tangible way. This aligns with the constructivist approach, which emphasizes active learning through interaction and experience. By enabling students to manipulate forces and observe real-time effects, the platform addresses the difficulty of visualizing abstract concepts, as outlined in the initial problem statement. For example, learners could experiment with Newton's laws and free fall motion in ways that traditional textbooks and classroom settings cannot replicate, fostering deeper comprehension through experiential learning.

6.2.2 Objective 2: To develop a metaverse-based learning platform for Physics using mixed reality technologies

The project successfully developed a fully functional metaverse-based learning platform, incorporating virtual and augmented reality for both hands-on experimentation and conceptual tutorial. The platform allowed learners to explore 3D models, conduct Physics experiments, and receive real-time feedback, which addressed the limitations of linear interface and physical space in traditional education. By fostering a non-linear and exploratory learning environment, students are encouraged to engage with content at their own pace, which not only enhances their understanding but also embodies the principles of constructivism. This constructivist approach cultivates a learner-centered environment, allowing students to take ownership of their learning journeys, actively construct knowledge through interaction, and develop a deeper comprehension of complex Physics concepts.

6.2.3 Objective 3: To evaluate the effectiveness of mixed reality technologies on students' learning performance in Physics education

Through usability testing with students and educators, the platform was shown to enhance engagement and learning performance. This ties back to the third problem statement regarding limited engagement in traditional Physics education. The use of interactive simulations, assessments, gamified elements, and collaborative learning spaces promotes active participation, aligning with the principles of the constructivist approach. The integration of mixed reality fostered a more engaging learning experience compared to standard classroom settings, leading to improved user satisfaction, which was measured through tools like the System Usability Scale (SUS) and Post-Study System Usability Questionnaire (PSSUQ). Participant feedback further substantiates that MR technologies not only enhance students' understanding and retention of Physics concepts but also align with the constructivist philosophy by creating a learner-centered environment where students can take ownership of their learning. The results confirmed the effectiveness of MR technologies in improving students' learning performance in Physics education.

In summary, the research findings demonstrated that MR technologies are highly effective in addressing the key problems in traditional Physics education and achieving the project's objectives. Through immersive, interactive, and engaging methods grounded in constructivism, the platform enhanced the learning experience, making abstract Physics concepts more accessible and understandable to students.

6.3 Problems Encountered

Several technical challenges arose during development.

6.3.1 Learning Curve in Unity and C#

The author began the project with limited experience in **Unity** and **C# programming**, which required significant effort to understand the libraries, programming logic, and functions necessary for development. The UI development process, in particular, involved extensive reliance on online resources, engaging in a continuous cycle of trial and error and persistent practice to solve issues and grasp how to effectively build the interface. This process demanded additional time to not only familiarize with the tools but also overcome challenges in understanding Unity’s complex components and architecture. Furthermore, the author faced a steep learning curve in working with 3D modeling and animation, both of which were entirely new concepts. As a result, the initial phases of the project were slower, particularly when integrating the various assets and components needed for interactive learning modules.

6.3.2 Scope Reduction Due to Time and Technical Constraints

Originally, the project aimed to cover more topics and content to make the application more comprehensive. However, due to time and technical constraints, the focus had to be narrowed down to only two topics: **Free Fall**

Motion and **Force**. Similarly, the planned **Augmented Reality (AR)** feature was not fully integrated. Although the author explored **Vuforia** as a foundational tool for AR, the time needed to learn and implement more complex, customized features was insufficient.

6.3.3 XR Interaction Toolkit Integration

A significant amount of time was spent integrating the **XR Interaction Toolkit** for the **experiment modules**. The complexity of developing scripts for the force and motion experiments, particularly for real-time visualization of Physics calculations, required continuous iteration. Ensuring the smooth functioning of the XR Interaction Toolkit while managing performance issues in larger environments posed significant technical challenges.

6.3.4 User Experience and Device Optimization

Managing user interactions within the metaverse-based learning environment required a balance between creating an immersive experience and maintaining user-friendliness. Designing an intuitive and accessible user interface sometimes conflicted with the immersive goals of the project. Additionally, optimizing the application for different devices was challenging, especially considering that **VR environments** tend to demand high-performance hardware. Performance optimization for a seamless experience on various platforms was an ongoing challenge throughout development.

6.4 Knowledge Gained

Throughout the development of *MetaPhysics*, the author gained valuable knowledge across several areas.

6.4.1 Usage of Development Tools

A significant amount of learning was focused on mastering the tools used to develop the application. The author gained proficiency in **Unity** and **C#**, understanding how to effectively implement interactive features using the **XR Interaction Toolkit** for VR functionality. In addition, the author learned how to create and manage **3D animations** to bring interactive elements to life, as well as how to design **user-friendly interfaces**. Integrating external tools like

Gather.Town to support the collaborative learning space module further expanded the author's skills in linking external platforms with Unity.

6.4.2 ADDIE Methodology

The process of applying the **ADDIE (Analysis, Design, Development, Implementation, and Evaluation)** methodology provided key insights into structured project development. By following this instructional design framework, the author learned how to systematically plan, design, develop, and implement the learning platform while incorporating continuous evaluation. This approach ensured that each phase was properly executed and aligned with the project's objectives.

6.4.3 Survey and Testing – Data Collection and Analysis

The author developed skills in conducting surveys and usability testing, particularly in educational contexts. Creating questionnaires for user requirement gathering and performance evaluation, as well as conducting System Usability Scale (SUS) and Post-Study System Usability Questionnaire (PSSUQ) testing, enabled the author to collect and analyze data effectively. This experience helped in understanding how to assess the usability, functionality, and user satisfaction of an application.

6.4.4 Research Skills

The author also honed research skills, particularly in finding and utilizing scholarly resources from platforms like Google Scholar and Mendeley. The author learned to critically evaluate sources, synthesize research findings, and apply them to the development of MetaPhysics application. This process further strengthened the author's academic research abilities and informed the project's design and implementation.

6.5 Limitations

The project faced several limitations that impacted its overall scope and user experience.

6.5.1 Limited Scope of Physics Topics and Depth of Content

The application focused on only two topics—Free Fall Motion and Force—due to time and resource constraints. While these topics were explored in depth, the author initially intended to include more topics and content to make the app more comprehensive and beneficial for users. However, the limitations in development time, alongside technical constraints, required the scope to be narrowed down.

6.5.2 Device Compatibility and Performance

The performance of the app is heavily reliant on the hardware capabilities of the user's device. As a Mixed Reality (MR) application, it requires more powerful hardware, storage, and memory to run efficiently. On less capable devices, users may experience slowdowns, crashes, or other issues that can impact the overall learning experience. Additionally, while the app was designed to be compatible with VR headsets and controllers for a more immersive experience, most users lacked access to this equipment. As a result, they could only use the app through a PC or laptop, which diminished the intended learning experience.

6.5.3 Battery Consumption

MR applications are known to have high power consumption, and this project was no exception. The app's battery usage was higher than that of typical educational applications, which could be a concern for users working on laptops or mobile devices with limited battery life, potentially affecting the continuity of learning sessions.

6.5.4 Multiplayer Functionality in Gather.Town

The collaborative learning space within the application, while offering interactive opportunities through Gather.Town, was limited in its player capacity. The multiplayer functionality did not fully support large-scale collaborative learning experiences, which restricted the number of simultaneous users who could actively engage with the collaborative space.

6.6 Future Enhancement

While the application has received favorable feedback from the majority of users, there remain several areas ripe for exploration and enhancement.

Identifying and addressing these areas will provide opportunities to refine the application further and expand its capabilities, ensuring an even more effective and engaging learning experience for all users.

6.6.1 Expansion of Physics Topics and Content

One of the key areas for future improvement is the expansion of topics covered within the application. Additional Physics concepts, such as electricity, magnetism, or waves, can be integrated into the platform, making it more comprehensive and beneficial for a wider range of students. Increasing the depth of content by including more advanced or complex modules within each topic would further enrich the learning experience.

6.6.2 Inclusion of Onboarding Guide

The platform could benefit from the inclusion of an onboarding guide to help new users navigate the various modules and features more easily. This guide would provide a step-by-step introduction to the platform’s functionalities, ensuring that users, especially those unfamiliar with mixed reality or metaverse environments, can quickly acclimate to the interface.

6.6.3 Enhanced AR and VR Functionality

Future versions could enhance the AR and VR capabilities of the application, offering smoother and more intuitive interactions, especially in the tutorial and experiment modules. The user interface could be further refined to provide more responsive and interactive elements, improving the overall user experience. Full compatibility with AR devices or VR headsets and controllers could also be prioritized to maximize the immersive potential.

6.6.4 Multiplayer and Collaborative Features

Expanding the capacity of the collaborative learning space to support more users at once could improve the social learning experience. Enhancements to the multiplayer functionality, such as larger collaborative sessions or more interactive features in the collaborative space, would allow for more dynamic group learning experiences.

6.6.5 Gamification and Leaderboard Features

To further enhance user engagement, future enhancements could involve expanding the gamification elements by introducing more badges, achievement systems, and competitive leaderboards. Additionally, incorporating more challenging quizzes and interactive assessments could provide students with a greater sense of accomplishment and foster healthy competition. These new features, combined with in-game rewards for participation and performance, could drive continuous engagement and motivation among students, further promoting a dynamic and interactive learning experience.

6.6.6 UI/UX Refinements

Continuous UI/UX improvements are essential to making the application more user-friendly and engaging. Refining the VR interfaces, improving UI responsiveness, and enhancing visual feedback when users interact with different elements can lead to a more seamless and enjoyable experience. Simplifying navigation and optimizing the menu design for both desktop and VR users can also enhance usability.

In conclusion, the project successfully met its objectives by developing an innovative and interactive learning platform for Physics, showcasing the power of mixed reality technologies in education. While there are areas for future improvement, the platform offers a promising solution to the challenges facing traditional Physics education, providing a more engaging and effective learning experience.

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APPENDICES

Appendix A: Questionnaire Google Form (User Requirement Gathering)

Survey Questionnaire on Exploring the Integration of Mixed Reality (MR) in Physics Education

Greetings!

I am student of Bachelor of Science (Honours) Software Engineering from Universiti Tunku Abdul Rahman (UTAR), currently conducting a survey regarding the integration of mixed reality (MR) technologies into Physics education.

This survey aims to gather insights from educators and learners regarding their experiences, preferences, and perceptions related to using MR in the classroom. If you are a Physics student or educator, then you are the right person for this! You are cordially invited to participate in this survey study. The results of this study should provide us with useful information in developing a mixed reality-based learning platform to enhance the learning experience for both educators and

learners, particularly in the realm of Physics education.

Completing this survey will take approximately 10-15 minutes. Your cooperation will be deeply appreciated!

Please be assured that the information you have provided is confidential and will be used solely for research purposes. Your personal details will not be shared or disclosed to any third parties.

For any inquiries, please feel free to reach out to: Agnes Tan Sze Wei - agnes.sze.wei@1utar.my

Your participation is greatly appreciated. Thank you, and may you have a wonderful day ahead!

agnes.sze.wei@1utar.my Switch account

Not shared

* Indicates required question

Personal Data Protection Act 2010

Please be informed that in accordance with Personal Data Protection Act 2010 ("PDPA") which came into force on 15 November 2013, Universiti Tunku Abdul Rahman ("UTAR") is hereby bound to make notice and require consent in relation to collection, recording, storage, usage and retention of personal information.

Acknowledgement of Notice *

- ◯ I have been notified and hereby understood, consented and agreed per UTAR notice.
- ◯ I disagree; my personal data will not be processed.

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Knowledge about Metaverse

Do you ever exposed to the concept "**METAVERSE**"? *

- ◯ Yes
- ◯ No
- ◯ Maybe

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Knowledge about Metaverse

What is your understanding of the term "METAVERSE"? *

- ☐ A virtual world with its own economy
- ☐ A network of interconnected virtual environments
- ☐ A single, immersive virtual reality environment
- ☐ A collection of online games and social platforms
- ☐ Other: ______

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What is Metaverse?

The "**Metaverse**" !
The metaverse is a **digital universe** where users interact through virtual reality (VR), augmented reality (AR),
mixed reality (MR), and other technologies.
In **AR**, digital elements are superimposed onto the real world, enhancing the user's perception of their environment.

VR transports users to entirely virtual worlds, providing a fully immersive experience through headsets and controllers.

MR combines elements of both AR and VR, seamlessly merging virtual and physical environments to create interactive and dynamic experiences.

Metaverse is a collective **virtual shared space** where users can interact with digital content, engage with others in real-time, and explore vast virtual landscapes, offering limitless possibilities for communication, collaboration, entertainment, and learning.

Section I

Are you currently a Physics **learner** or **educator**? *

- ◯ Physics learner
- ◯ Physics educator
- ◯ None of the above

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Section II (Physics Learner) - Demographic Information

Form/Grade/Level *
(e.g., Form 4, 11th grade, Diploma, Degree, Master, etc.)

Your answer

Institution/School Name

Your answer

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Section II (Physics Educator) - Demographic Information

Institution/Organization Name

Your answer

Role/Position *

Your answer

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Section II - Demographic Information

Occupation *

Choose

Age group *

- below 16
- 16 - 17
- 18 - 23
- above 23

Section II (b) - Knowledge to Physics

When was the last time you interacted with Physics concepts or topics? *

- Within the last month
- Within the last 3 months
- Within the last 6 months
- Within the last year
- More than a year ago
- Never interacted with physics concepts

How would you rate your overall understanding of Physics concepts? *

	1	2	3	4	5	
Very poor	○	○	○	○	○	Very good

Have you ever used educational apps, simulations or platforms for learning purposes? *
(e.g., Duolingo, PhET, Coursera, ...)

- Yes
- No

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Section III (Physics Learner) - Difficulty in Learning Physics

This section includes (9) questions related to your current personal experience in learning Physics.

On a scale of 1 to 5, how do you **feel** about your current experience with learning Physics in the classroom? *

	1	2	3	4	5	
Very dissatisfied	○	○	○	○	○	Very satisfied

What **aspects** of Physics education do you find most engaging or interesting? *

- ☐ Hands-on experiments
- ☐ Interactive simulations
- ☐ Group discussions
- ☐ Lectures
- ☐ Other: ____________

What **challenges** do you encounter when trying to understand complex Physics concepts? *

- ☐ Lack of clarity from educators
- ☐ Difficulty visualizing concepts
- ☐ Insufficient practice opportunities
- ☐ Other: ____________

How do you prefer to learn new material? *

- [ ] Hands-on experiments
- [ ] Interactive simulations
- [ ] Group discussions
- [ ] Lectures
- [ ] Other: __________

Have you ever used educational apps, simulations or platforms for learning purposes? *

- ○ Yes
- ○ No

If yes, how would you describe your feelings about the **interface** of the educational app/simulation/platform you have used or are considering using? *

- [ ] User-friendly
- [ ] Intuitive
- [ ] Engaging
- [ ] Confusing
- [ ] Overwhelming
- [ ] Boring
- [ ] Unreal
- [ ] Laggy
- [ ] Difficult to use
- [ ] Other: __________

What are your **thoughts** on using immersive technologies (e.g., MR, VR, AR) to explore Physics concepts in a virtual environment? *

- ○ Excited to explore
- ○ Open to the idea
- ○ Unsure
- ○ Not interested

Do you think integrating mixed reality technologies into Physics education would enhance your learning experience? *

- ○ Yes, it would enhance learning
- ○ No, it would not enhance learning
- ○ Unsure

Have you ever experienced mixed reality (MR), virtual reality (VR) or augmented reality (AR) technologies for educational purposes? *

- ○ Yes, positive experience
- ○ Yes, negative experience
- ○ Yes, mixed experience
- ○ No, but interested
- ○ No, not interested

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Section III (Physics Educator) - Difficulty in Teaching Physics

This section includes (10) questions related to your current personal experience in teaching Physics.

On a scale of 1 to 5, how do you feel about your current experience with teaching Physics in the classroom? *

	1	2	3	4	5	
Very dissatisfied	○	○	○	○	○	Very satisfied

What are the main challenges you face in teaching Physics concepts effectively? *

- ☐ Limited student engagement
- ☐ Difficulty explaining complex concepts
- ☐ Lack of access to resources
- ☐ Difficulty visualizing real life example
- ☐ Other: ____________

How do you prefer to deliver new material? *

- ☐ Hands-on experiments
- ☐ Interactive simulations
- ☐ Group discussions
- ☐ Lectures
- ☐ Other: ____________

How do you assess students' understanding and progress in Physics education? *

- ☐ Written exams
- ☐ Practical experiments
- ☐ Class participation
- ☐ Quizzes
- ☐ Other: ____________

What specific Physics topics do you find most challenging to teach using traditional methods? *

- ☐ Mechanics
- ☐ Electricity & magnetism
- ☐ Thermodynamics
- ☐ Quantum mechanics
- ☐ Other: ____________

How regularly are technologies and interactive learning tools incorporated into your Physics curriculum? *

- ○ Regularly used
- ○ Occasionally used
- ○ Rarely used
- ○ Not used

What technology and interactive learning tools have you incorporated into your Physics curriculum? (if any, please specify)

Your answer

What are your thoughts on using immersive technologies (e.g., MR, VR, AR) to explore Physics concepts in a virtual environment? *

- ◯ Excited to explore
- ◯ Open to the idea
- ◯ Unsure
- ◯ Not interested

Do you think integrating mixed reality technologies into Physics education would enhance students' learning performance? *

- ◯ Yes, it would enhance learning
- ◯ No, it would not enhance learning
- ◯ Unsure

Have you experimented with mixed reality (MR), virtual reality (VR) or augmented reality (AR) technologies in your teaching methods? *

- ◯ Yes, positive experience
- ◯ Yes, negative experience
- ◯ Yes, mixed experience
- ◯ No, but interested
- ◯ No, not interested

Section III - Difficulty in Using Educational Applications

This section includes (5) questions related to your current personal experience in using educational applications.

What type of educational apps, simulations or platforms have you used? *

- [ ] Language learning
- [ ] Mathematics
- [ ] Science
- [ ] History
- [ ] Arts and humanities
- [ ] Other: ____________

On a scale of 1 to 5, what is your overall learning experience using educational app / simulation / platform? *
(rate based on the application that is most related to physics)

	1	2	3	4	5	
Very dissatisfied	○	○	○	○	○	Very satisfied

How would you describe your feelings about the interface of the educational app/simulation/platform you have used or are considering using? *

- [ ] Usability (User-friendly)
- [ ] Intuitive
- [ ] Engaging
- [ ] Confusing
- [ ] Overwhelming
- [ ] Boring
- [ ] Unreal
- [ ] Laggy
- [ ] Difficult to use
- [ ] Other: ____________

What challenges do you encounter when trying to understand new concepts using the app/simulation/platform? *

- [ ] Lack of detailed explanation
- [ ] Difficulty visualizing concepts
- [ ] Insufficient practice opportunities
- [ ] Other: ____________

Have you ever experienced with mixed reality (MR), virtual reality (VR) or augmented reality (AR) technologies in any field? *

- ◯ Yes, positive experience
- ◯ Yes, negative experience
- ◯ Yes, mixed experience
- ◯ No, but interested
- ◯ No, not interested

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Section IV (Learners & Educators) - Personal Experience towards Immersive Technologies

This section includes (6) questions related to your personal experience in using immersive technologies for educational purposes.

Have MR-integrated learning methods improved your learning / teaching experience compared to traditional learning methods? *

- ◯ Yes
- ◯ No

If yes, what are the notable **modules / features / functions** that enhanced your learning / teaching experience? *

- ☐ Demonstration / tutorial
- ☐ Virtual hands-on experiment
- ☐ Interactive simulations
- ☐ Assessment / quizzes
- ☐ Gamified elements
- ☐ Virtual collaborative learning space
- ☐ None
- ☐ Other: ____________

How do these notable features **positively impact** students' learning experience? *

- [ ] Increased engagement in learning activities
- [ ] Greater motivation to learn
- [ ] Better assessment of student progress
- [ ] Enhanced understanding of concepts
- [ ] Improved retention of information
- [ ] Inspired curiosity and critical thinking
- [ ] None
- [ ] Other: ______________________

What are your thoughts on the current **interface** of mixed reality (MR) applications or platforms you have used? *

- [ ] Usability (User-friendly)
- [ ] Realistic
- [ ] Intuitive
- [ ] Engaging
- [ ] Confusing
- [ ] Overwhelming
- [ ] Unstable
- [ ] Difficult to use
- [ ] Other: ______________________

What **challenges** have you faced while using mixed reality for learning / teaching? *

- ☐ Technical difficulties or limitations
- ☐ Limited access to MR devices
- ☐ Lack of training on using MR technology
- ☐ Comfort issues
- ☐ Resistance to change
- ☐ Limited content availability
- ☐ Social Isolation
- ☐ Delayed interactive responses
- ☐ Lack of real sensual experience
- ☐ Inaccurate movement detection
- ☐ Other: ____________________

How do you think mixed reality technologies can be improved to better support students' learning needs? *

- ☐ More diverse content
- ☐ Enhanced user-friendliness
- ☐ Better technical support
- ☐ Increased collaboration opportunities
- ☐ Improved accessibility
- ☐ More realistic & accurate sensual experience
- ☐ Improved movement detection
- ☐ On-time interactive response
- ☐ Other: ____________________

Section IV - Personal Experience towards Immersive Technologies

This section includes (6) questions related to your personal experience in using immersive technologies.

In which field have you primarily used mixed reality (MR) technology? *

- ☐ Entertainment
- ☐ Education
- ☐ Sports
- ☐ Work
- ☐ Other: ____________

Have you found mixed reality (MR) technology beneficial in your experience? *

- ○ Yes
- ○ No
- ○ Maybe

If yes, how has mixed reality (MR) technology benefited you? *

- [ ] Enhanced learning experiences in education
- [ ] Improved training and skill development in professional settings
- [ ] Enhanced visualization and understanding of complex concepts
- [ ] Increased efficiency and productivity in work tasks
- [ ] Enhanced collaboration and communication with others
- [ ] Improved problem-solving abilities
- [ ] More lifelike and immersive experiences
- [ ] Increased creativity and innovation
- [ ] None
- [ ] Other: ______________________

What are your thoughts on the current interface of mixed reality (MR) applications or platforms you have used? *

- [ ] Usability (User-friendly)
- [ ] Realistic
- [ ] Intuitive
- [ ] Engaging
- [ ] Confusing
- [ ] Overwhelming
- [ ] Unstable
- [ ] Difficult to use
- [ ] Other: ______________________

What challenges have you encountered while using mixed reality (MR) technology? *

- ☐ Technical issues (e.g., glitches, lag)
- ☐ Complexity of setup and use
- ☐ Lack of training on using MR technology
- ☐ Comfort issues
- ☐ Limited content or applications availability
- ☐ Social Isolation
- ☐ Delayed interactive responses
- ☐ Lack of real sensual experience
- ☐ Inaccurate movement detection
- ☐ Other: ____________

In your opinion, what improvements do you think are needed for mixed reality (MR) applications or platforms? *

Your answer ____________

Section IV (Physics Educator) - Opinions towards Immersive Technologies

This section includes (4) questions related to your opinion in integrating immersive technologies in the classroom.

What concerns or reservations do you have about adopting mixed reality technologies in the classroom? *

- ☐ Technical difficulties or limitations
- ☐ Cost of implementing MR technology
- ☐ Lack of training
- ☐ Resistance to change
- ☐ Limited content availability
- ☐ Comfort and safety concerns
- ☐ Social Isolation
- ☐ Other: ____________

What factors would encourage you to integrate mixed reality technologies into your teaching? *

- ☐ Improved student engagement
- ☐ Enhanced learning outcomes
- ☐ Availability of relevant content
- ☐ Enhanced visualization of abstract concepts
- ☐ Better assess of student performance
- ☐ Technical support
- ☐ Collaboration opportunities
- ☐ Other: ____________

What resources or support would you need to effectively implement mixed reality-based learning activities in your teaching? *

- [ ] Access to MR devices
- [ ] Training on MR technology
- [ ] Curriculum development support
- [ ] Other: ____________________

How do you think mixed reality-based learning activities could benefit students with different learning styles or abilities? *

- ◯ Cater to visual learners
- ◯ Engage kinesthetic learners
- ◯ Benefit auditory learners
- ◯ Accommodate diverse learning preferences (All of the above)

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Section IV (Physics Learner) - Opinions towards Immersive Technologies

This section includes (4) questions related to your opinion in integrating immersive technologies in the classroom.

On a scale of 0 to 5, how familiar are you with mixed reality technologies (MR, VR, AR)? *

	1	2	3	4	5	
Not familiar at all	◯	◯	◯	◯	◯	Very familiar

How do you think mixed reality (MR), virtual reality (VR) or augmented reality (AR) technologies can improve learning experience? *

- [ ] Increased interactivity
- [ ] Better understanding of complex concepts
- [ ] Enhanced motivation
- [ ] Improved collaboration
- [ ] More engaging learning materials
- [ ] Other: ____________________

What concerns or reservations do you have about learning using mixed reality technologies in the classroom? *

- ☐ Technical difficulties or limitations
- ☐ Cost of implementing MR technology
- ☐ Lack of training
- ☐ Resistance to change
- ☐ Limited content availability
- ☐ Comfort and safety concerns
- ☐ Social Isolation
- ☐ Other: ______

What resources or support would you need to effectively implement mixed reality-based learning activities in your learning? *

- ☐ Access to MR devices
- ☐ Training on MR technology
- ☐ Curriculum development support
- ☐ Other: ______

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Section IV - Opinions towards Immersive Technologies

This section includes (4) questions related to your opinion in using immersive technologies for educational purpose.

On a scale of 0 to 5, how familiar are you with mixed reality technologies (MR, VR, AR)? *

	1	2	3	4	5	
Not familiar at all	○	○	○	○	○	Very familiar

What are your thoughts on using immersive technologies (e.g., MR, VR, AR) to explore educational concepts in a virtual environment? *

- ○ Excited to explore
- ○ Open to the idea
- ○ Unsure
- ○ Not interested

What concerns or reservations do you have about using immersive technology in education? *

- [ ] Technical difficulties or limitations
- [ ] Cost of implementing MR technology
- [ ] Lack of training
- [ ] Resistance to change
- [ ] Limited content availability
- [ ] Comfort and safety concerns
- [ ] Social Isolation
- [ ] Other: ____________

What factors would encourage you to integrate mixed reality (MR) technologies into your learning or teaching experience? *

- [ ] Enhanced engagement
- [ ] Improved understanding of complex concepts
- [ ] Access to immersive learning experiences
- [ ] Opportunities for interactive and hands-on learning
- [ ] Opportunities for collaboration and teamwork
- [ ] Alignment with modern educational trends
- [ ] Ability to cater to diverse learning styles
- [ ] Potential for personalized learning experiences
- [ ] Other: ____________

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Section V (Functions & Features)

This section includes (6) questions related to your opinions regarding functions and features that you expected to see in the metaverse-based learning platforms.

What features or functionalities would you like to see in a mixed reality-based Physics learning platform? (e.g., collaboration tools, interactive simulations, ...) *

- [ ] Customizable learning paths
- [ ] Collaborative learning spaces
- [ ] Interactive simulations
- [ ] Real-time feedback
- [ ] Progress tracking and assessment
- [ ] Teacher dashboard and analytics
- [ ] Augmented reality annotations
- [ ] Other: ______________________

How do you envision the ideal balance between traditional teaching methods and technology-enhanced learning experiences in Physics education? *

- ○ Mostly traditional methods
- ○ Balanced mix of traditional and technology-enhanced methods
- ○ Mostly technology-enhanced methods with minimal traditional teaching

Are there any specific Physics concepts or topics that you believe would be particularly well-suited for exploration using mixed reality technologies? *

- [ ] Mechanics
- [ ] Thermodynamics
- [ ] Electricity & magnetism
- [ ] Quantum mechanics
- [ ] Other: ______

What potential **benefits** do you see in using metaverse-based learning platforms? *

- [ ] Real-time collaboration
- [ ] Personalized learning experiences
- [ ] Global connections
- [ ] Enhanced assessment and feedback
- [ ] Improved learning outcomes
- [ ] Other: ______

What potential **drawbacks** do you see in using metaverse-based learning platforms? *

- [ ] Technical difficulties
- [ ] Privacy concerns
- [ ] Social isolation
- [ ] Limited accessibility
- [ ] Slowed down learning process
- [ ] Other: ______

Additional recommendations / feedback (if any)

Your answer ______

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Appendix B: Questionnaire of System Usability Scale (SUS)

1. I think that I would like to use this system frequently.
2. I found the system unnecessarily complex.
3. I thought the system was easy to use.
4. I think that I would need the support of a technical person to be able to use this system.
5. I found the various functions in this system were well integrated.
6. I thought there was too much inconsistency in this system.
7. I would imagine that most people would learn to use this system very quickly.
8. I found the system very cumbersome to use.
9. I felt very confident using the system.
10. I needed to learn a lot of things before I could get going with this system.

Appendix C: Post-Study System Usability Questionnaire (PSSUQ)

1. Overall, I am satisfied with how easy it is to use this system.
2. It was simple to use this system.
3. I was able to complete the tasks and scenarios quickly using this system.
4. I felt comfortable using this system.
5. It was easy to learn to use this system.
6. I believe I could become productive quickly using this system.
7. The system gave error messages that clearly told me how to fix problems.
8. Whenever I made a mistake using the system, I could recover easily and quickly.
9. The information (such as online help, on-screen messages, and other documentation) provided with this system was clear.
10. It was easy to find the information I needed.
11. The information was effective in helping me complete the tasks and scenarios.
12. The organization of information on the system screens was clear.
13. The interface of this system was pleasant.
14. I liked using the interface of this system.
15. This system has all the functions and capabilities I expect it to have.
16. Overall, I am satisfied with this system.

Appendix D: Questionnaire Google Form of Usability Testing

Usability Testing: Metaverse-based Physics Learning Platform

Greetings!

I am student of Bachelor of Science (Honours) Software Engineering from Universiti Tunku Abdul Rahman (UTAR), currently conducting a usability testing for the Metaverse-based Physics Learning Platform.
Thank you for participating in the usability testing for the Metaverse-based Physics Learning Platform. Your feedback is essential in helping us assess and improve the platform. This form consists of two parts:

1. ***System Usability Scale (SUS)****: A quick 10-item questionnaire to measure your overall experience using the platform.*
2. ***Post-Study System Usability Questionnaire (PSSUQ)****: A 19-item survey to gauge system usefulness, information quality, and interface quality.*

At the end of the form, please share any additional opinions or feedback you may have about the platform. Your responses will be kept confidential and used solely for improving the system.
For any inquiries, please feel free to reach out to: Agnes Tan Sze Wei - agnes.sze.wei@1utar.my

Your participation is greatly appreciated. Thank you, and may you have a wonderful day ahead!

agnes.sze.wei@1utar.my Switch account

Not shared

Personal Data Protection Act 2010
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Acknowledgement of Notice

- ○ I have been notified and hereby understood, consented and agreed per UTAR notice.
- ○ I disagree; my personal data will not be processed.

Testing Environment

How did you perform the testing? *

- ○ I performed the testing physically.
- ○ I performed the testing remotely (with control access).
- ○ I performed the testing remotely (by watching a demonstration video).

Assessment Scores

1. What was your score in the *Free Fall Motion* assessment module? *
(Total: 7 questions)

Your answer

1. What was your score in the *Force* assessment module? *
(Total: 8 questions)

Your answer

Section 1: System Usability Scale (SUS)

For each of the following statements, please rate your level of agreement on a scale from 1 (**Strongly Disagree**) to 5 (**Strongly Agree**).

1. I think that I would like to use this system frequently. *

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

2. I found the system unnecessarily complex. *

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

3. I thought the system was easy to use. *

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

4. I think that I would need the support of a technical person to be able to use this system. *

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

5. I found the various functions in this system were well integrated. *

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

6. I thought there was too much inconsistency in this system. *

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

7. I would imagine that most people would learn to use this system very quickly. *

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

8. I found the system very cumbersome to use. *

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

9. I felt very confident using the system. *

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

10. I needed to learn a lot of things before I could get going with this system. *

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

Section 2: Post-Study System Usability Questionnaire (PSSUQ)

Please rate the following statements on a scale from 1 (**Strongly Agree**) to 7 (**Strongly Disagree**).

1. Overall, I am satisfied with how easy it is to use this system. *

	1	2	3	4	5	6	7	
Strongly Agree	○	○	○	○	○	○	○	Strongly Disagree

2. It was simple to use this system. *

	1	2	3	4	5	6	7	
Strongly Agree	○	○	○	○	○	○	○	Strongly Disagree

3. I was able to complete the tasks and scenarios quickly using this system. *

	1	2	3	4	5	6	7	
Strongly Agree	○	○	○	○	○	○	○	Strongly Disagree

4. I felt comfortable using this system. *

	1	2	3	4	5	6	7	
Strongly Agree	○	○	○	○	○	○	○	Strongly Disagree

5. It was easy to learn to use this system. *

	1	2	3	4	5	6	7	
Strongly Agree	○	○	○	○	○	○	○	Strongly Disagree

6. I believe I became productive quickly using this system. *

	1	2	3	4	5	6	7	
Strongly Agree	○	○	○	○	○	○	○	Strongly Disgree

7. The system gave error messages that clearly told me how to fix problems. *

	1	2	3	4	5	6	7	
Strongly Agree	○	○	○	○	○	○	○	Strongly Disagree

8. Whenever I made a mistake using the system, I could recover easily and quickly. *

	1	2	3	4	5	6	7	
Strongly Agree	○	○	○	○	○	○	○	Strongly Disagree

9. The information (such as online help, on-screen messages, and other documentation) provided with this system was clear. *

	1	2	3	4	5	6	7	
Strongly Agree	○	○	○	○	○	○	○	Strongly Disagree

10. It was easy to find the information I needed. *

	1	2	3	4	5	6	7	
Strongly Agree	○	○	○	○	○	○	○	Strongly Disagree

11. The information provided for the system was easy to understand. *

	1	2	3	4	5	6	7	
Strongly Agree	○	○	○	○	○	○	○	Strongly Disagree

12. The organization of information on the system screens was clear. *

	1	2	3	4	5	6	7	
Strongly Agree	○	○	○	○	○	○	○	Strongly Disagree

13. The interface of this system was pleasant. *

	1	2	3	4	5	6	7	
Strongly Agree	○	○	○	○	○	○	○	Strongly Disagree

14. I liked using the interface of this system. *

	1	2	3	4	5	6	7	
Strongly Agree	○	○	○	○	○	○	○	Strongly Disagree

15. This system has all the functions and capabilities I expect it to have. *

	1	2	3	4	5	6	7	
Strongly Agree	○	○	○	○	○	○	○	Strongly Disagree

16. Overall, I am satisfied with this system. *

	1	2	3	4	5	6	7	
Strongly Agree	○	○	○	○	○	○	○	Strongly Disagree

Back Next Clear form

Section 3: Feelings Towards Immersive-based Education Methods

1. How do you feel about using immersive-based education methods (e.g., Virtual Reality or Augmented Reality) compared to traditional learning methods (e.g., textbooks, lectures)? *

	1	2	3	4	5	
Much Worse	○	○	○	○	○	Much Better

2. In terms of enhancing learning performance, how does immersive-based education (this application) helps compare to traditional methods? *

	1	2	3	4	5	
Much Worse	○	○	○	○	○	Much Better

3. Do you believe immersive-based education helps you understand complex Physics concepts better than traditional methods? *

	1	2	3	4	5	
Strongly Disagree	○	○	○	○	○	Strongly Agree

Opinions, **feedback**, or **suggestions** for improving the platform based on your experience.

Your answer